TPO-RGN-1003
AAA-PDO-GEN-01-0035
LA-UR-01-2834
Revision 0
April 2001

Advanced Accelerator Applications
Technical Note
Technology Project Office

ADTF Linac Review
April 10-12, 2001

ADTF Linac Review
April 10-12, 2001

Document Number:
TPO-RGN-1003
AAA-PDO-GEN-01-0035
LA-UR-01-2834
Revision 0

Category: 1

Abstract:

This document contains information presented at the April 10-12, 2001, project review of the Accelerator-Driven Test Facility (ADTF). The purpose of this information is to review accelerator-related requirements and assess their impact on LINAC approach; to review applicability of APT accelerator design to the ADTF linac; to assess the technical readiness of key ADTF accelerator components such as the coupled-cavity drift-tube linac and low-energy superconducting elements, particularly spoke resonator technology and $\beta = 0.48$ elliptical cavity; to recommend a strategy for proceeding with ADTF linac design and the technology effort; and to comment on impacts the recommended strategy may have on program deliverables.

Approval:

Project Leader	Signature on file 6/4/01
AAA/TPO	Rich Sheffield / Date

Distribution List

APT-RMDC	C341
AAA Project Office	H816
Quintana, Lawrence (QA)	H805
Rich Sheffield	H816
John McGill	H816

Table of Contents

Agenda

Los Alamos National Laboratory

ADTF LINAC Review

April 10-12, 2001

Location: TA-53, Bldg. 31
Pinon Conference Room

April 10

8:30 - 8:45	Welcome Remarks and Charge to Committee	Ed Arthur
8:45 - 9:15	Overview of APT and ADTF LINAC Requirements and Designs	Rich Sheffield
	ADTF Requirements and Schedule	
9:15 - 10:00	T/M Design and Resulting Requirements	Mike Cappiello
10:00 - 10:10	BREAK	
10:10 - 10:50	ADTF Accelerator Requirements	Dave Schneider
10:50 - 11:00	Schedule	Steve McConnell
	APT-Based Systems Common to All Proposed ADTF Accelerator Options	
11:00 - 11:30	Performance of LEDA Injector and RFQ Relative to ADTF Requirements (covering design status, and cost and schedule of remaining ED&D)	Dave Schneider
11:30 - 12:00	Superconducting beta=0.64 Design for ADTF	Mike McCarthy
12:00 – 2:00	Working Lunch (LEDA Conf. Rm. TA-53, Bldg. 365) (with tour of LEDA and CCDTL)	

ADTF Reference LE LINAC Design Description

2:00 - 2:15	Beam Dynamics	Robert Garnett
2:15 - 3:00	CCDTL and CCL Architecture (covering design status, and cost and schedule of remaining CCDTL ED&D)	Rick Wood
3:00 - 3:15	BREAK	
3:15 - 4:15	Continued - CCDTL and CCL Architecture	Rick Wood
4:15 - 5:00	RF Design Options	Mike McCarthy

April 11

Alternative Superconducting LE LINAC Design Description

8:15 - 9:05	Superconducting Architectures (with and without spoke cavity)	Tom Wangler
9:05 - 9:45	Beam Dynamics	Robert Garnett
9:45 -10:00	BREAK	
10:00 -10:45	RF Design Options	Dan Rees
10:45- 11:30	Expected Reliability/Availability of Proposed Design	Kris Kerns
11:30- 12:30	Cost Study Results (Advanced Energy Sytems)	John Rathke
12:30 - 1:30	Working Lunch (Pinon Conf. Rm. TA-53, Bldg. 31)	

SC Techinical Status/Plans

1:30 - 1:50	Beta=0.48 Design Status, Cost, and Schedule	Dominic Chan
1:50 - 2:05	Spoke Cavity Introduction	Dale Schrage
2:05 - 2:25	ANL Spoke Cavity Tests	Tsuyoshi Tajima
2:25 - 2:45	Design of Spoke Cavity	Frank Krawczyk
2:45 - 3:05	Design of Power Coupler	Eric Schmierer
3:05 - 3:20	BREAK	
3:20 - 3:40	Cryomodules and Plant	Patrick Kelley
3:40 - 4:15	Spoke Cavity Issues, Cost, Schedule and ED&D Plan	Dale Schrage

Summary of ADTF Designs

4:15 - 4:45	Performance and Reliability Summary, and 100 mA Capability Impacts	Rich Sheffield
4:45 - 5:00	Transition Issues, Cost, and Schedule Comparisons	Rich Sheffield

April 12

8:30 -12:00	One on One Discussions and Panel Internal Discussion
12:00 - 1:00	Working Lunch (Pinon Rm. TA-53, Bldg. 31)
1:00 - 2:00	Report of Panel and Concluding Remarks
3:00 - 4:15	Seminar on Halo Measurements (Orange-Box Conf. Rm. TA-53, Bldg. 6)

Accelerator Driven Test Facility
LINAC Review

April 10-12, 2001

Review Committee Charge

Edward D. Arthur
AAA
Los Alamos National Laboratory

AAA

Charge

- Review ADTF accelerator-related requirements and assess their impact on LINAC approach

- Review applicability of APT accelerator design to ADTF LINAC

- Assess technical readiness of key ADTF accelerator components
  - CCDTL
  - Low-energy superconducting elements, particularly spoke resonator technology and β =0.48 elliptical cavity
  - Other as appropriate

- Recommend a strategy for proceeding with ADTF LINAC design and technology effort

- Comment on impacts the recommended strategy may have on program deliverables (schedule goal for ADTF, tritium backup, ...)

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 — 12, 2001

Overview of APT and ADTF Linac Requirements and Designs

Rich Sheffield

APT FUNCTION: SAFELY PRODUCE TRITIUM TO MEET DOE NEEDS

Performance Requirements

¥ Produce up to 1.5 kg of tritium per year for a minimum of 40 years.

¥ Employ modular design that is upgradeable to 3 kg/yr or down-gradeable to 1 kg/yr.

¥ Protect public, workers, and environment from radiation, toxic, and industrial impacts; comply with DOE, federal, state,and local regulatory requirements.

¥ Optimize design for lowest capital and operating costs with accept-able technical risk.

Reference Design Solution

¥ Proton RF linear accelerator

¥ Output energy nominally 1030 MeV, upgradeable to 1700 MeV.

¥ Output current nominally 100 mA CW

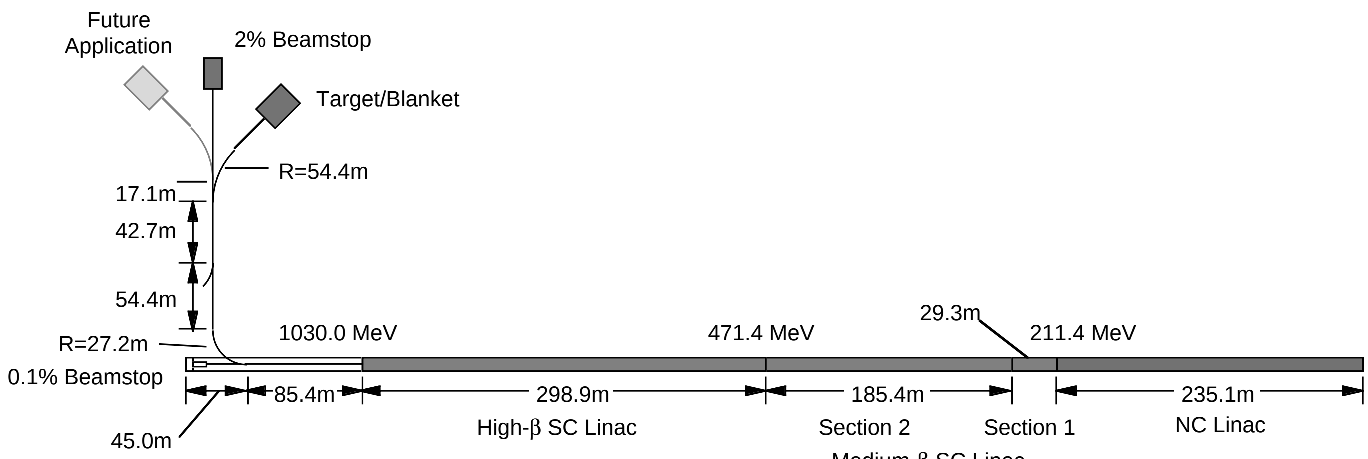
¥ Robust target/blanket for neutron and tritium production (trip fault insensitive)

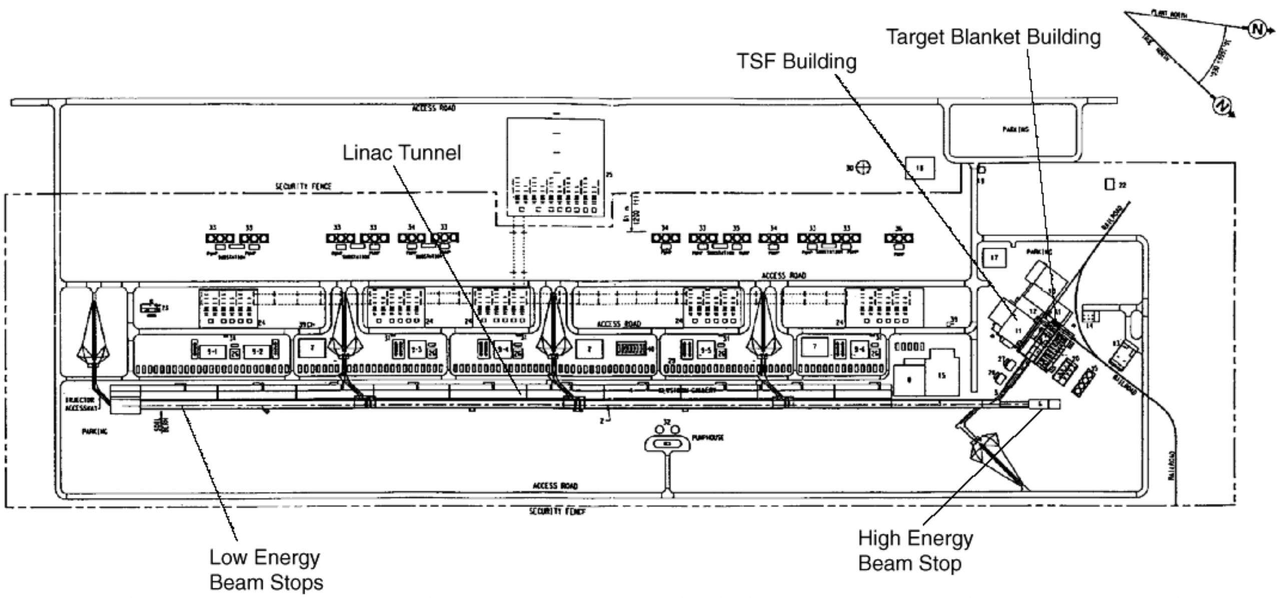
¥ Tritium production from neutron capture in ^{3}He gas feedstock

¥ Tritium recovery from ^{3}He gas stream using permeation and cryo-distillation

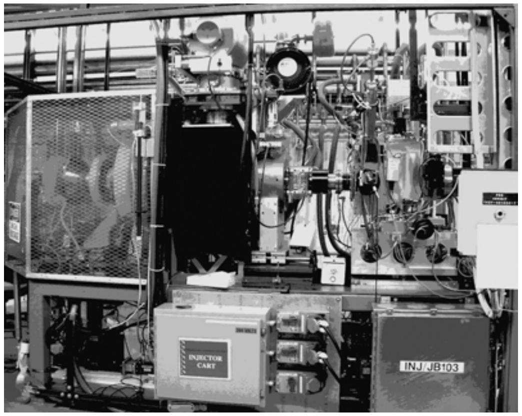
¥ Plant availability of at least 72%

APT LAYOUT FOR THE 1 GeV, 100 mA APT ACCELERATOR AND TARGET

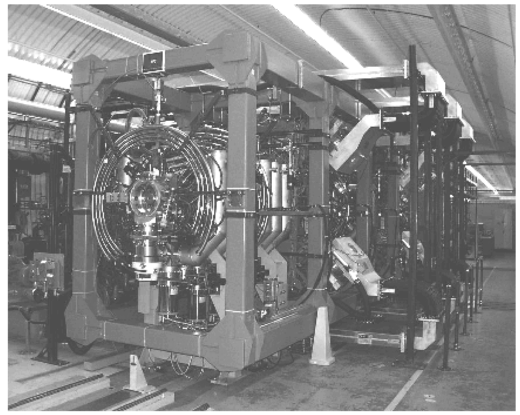




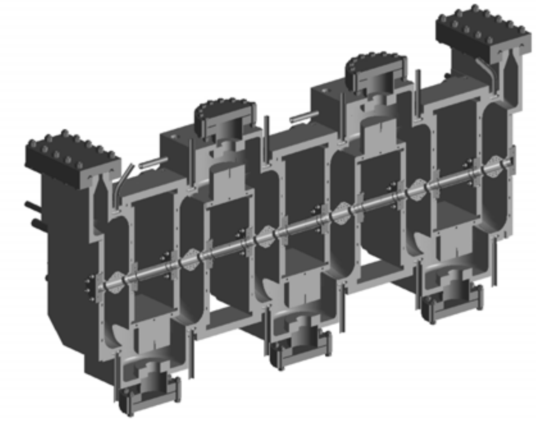
APT LINAC MAJOR ACCLERATOR COMPONENTS



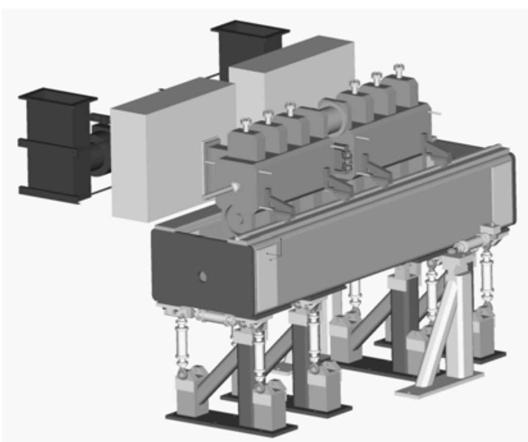
Photograph of LEDA H+ injector including LEBT (Low Energy Beam Transport)



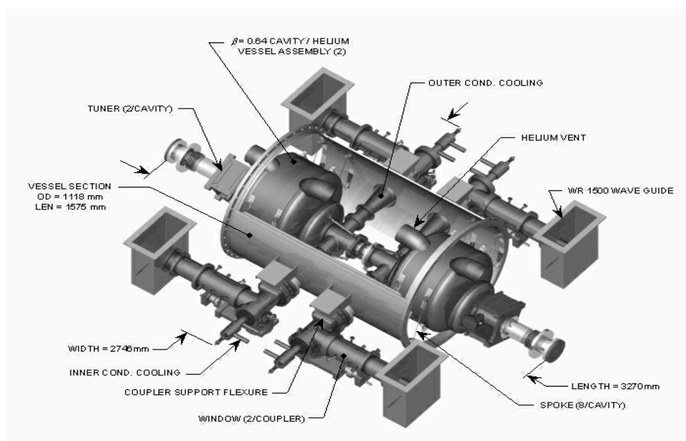
Photograph of LEDA RFQ



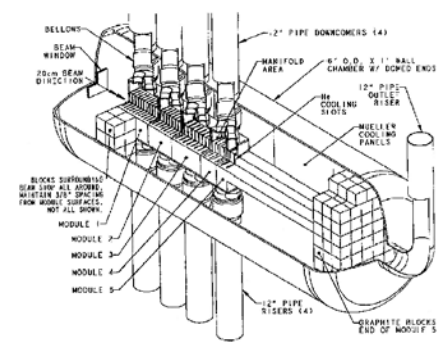
Representative CCDTL structure



Representative CCL structure



Two-cavity cryomodule isometric with shell cutaway.



High-energy beamstop vessel layout

THE ADTF REQUIREMENTS IMPACT ACCELERATOR DESIGN IMPLYING A MODIFICATION OF THE APT ACCELERATOR DESIGN FOR ADTF

- Significant progress has been made on the CCDTL and CCL.
- Advances in superconducting technology combined with the lower beam current of ADTF makes the application of superconducting technology more compelling.
- Initial discussions with T/M designers identified T/M intolerance to interrupts > 0.3s. The APT design must be modified to provide higher reliability.

MAJOR ISSUES

- What are the ADTF requirements for reliability, current stability and control, power, and beam sharing (isotopes)? Present schedule has T/M requirements defined at the end of this calendar year. (T/M)
- Tritium mission: what does it mean for ADTF? (DOE)
- To what extent is this accelerator meant to be an ATW prototype? (DOE)
- What extra investment is required for 100 mA compatibility?

SIMILARITIES BETWEEN APT AND ADTF ACCELERATOR DESIGNS

AAA

- High-power CW proton beam (MWs)
- No issues arose on major portions of the linac because the design of the present components is current independent and the same design would be used. In particular, the RFQ and the 211 MeV to 600 MeV superconducting portion of the linac are planned to be incorporated into the ADTF design.
- Availability requirement is similar.

ADTF MISSION AS STATED IN THE CONGRESSIONAL REPORT

- Technology options for the transmutation of spent nuclear fuel and waste through a series of integrated experiments aimed at demonstrating the performance and practicality of the proposed technologies.
- Safe operation of a complete system, coupling an accelerator, sub-critical reactor, target, fuel, and balance of plant systems, both in normal and abnormal conditions. (Imposes new req. s)
- The capability, through upgrades or additions, to produce tritium for national security purposes, if required. (Forces additional constraints)
- A user facility that allows testing of advanced nuclear materials and fuels, materials science research, experimental physics, and conventional nuclear engineering applications. (Imposes new req. s)

The engineering challenges in the ADTF lie in the safe, controlled coupling of an accelerator to a sub-critical reactor through a spallation target. System control and safe operation will demand the understanding and resolution of the potentially complex behavior of this coupled accelerator/target/reactor system.

SIGNIFICANT DIFFERENCES BETWEEN APT AND ADTF ACCELERATOR DESIGNS

- The interaction between the sub-critical multiplier and the accelerator adds a significant level of design complexity that did not exist in the APT design (safety and SCM vulnerabilities).
- Operating costs can drive design.
- APT and ADTF have different beam requirements:
  - —Less than 1/7 the beam current and than 60%of the beam energy
  - —Imposition of a stringent beam reliability requirement
- The ADTF may require beam sharing.

ADTF LINAC DESIGN OPTIONS

- ¥ Use APT design, i.e. build machine with no modifications and with full 100 mA capability ab initio.
  - —Highest cost
  - —Least ED&D effort
  - —Shortest implementation
- ¥ Optimize the APT design for ADTF beam requirements considering some changes in linac architecture.
  - —Lower cost
  - —Meets schedule
- ¥ Design from scratch and only consider less than 20 mA maximum current.
  - —Lowest cost option
  - —Uncertain schedule impact
  - —Uncertain ED&D costs

OPTIMIZED ADTF LINAC DESIGN OPTIONS TO BE CONSIDERED

AAA

1. Optimize CCDTL and CCL linac structure to minimize RF power for 13 mA operation while being compatible with 100 mA future operation — Presently in process.
2. Optimized 13 mA operation by replacing CCL with β=0.48 elliptical superconducting structure while maintaining possibility for 100 mA future operation.
3. Optimized 13 mA operation by replacing CCL with β=0.48 elliptical superconducting structure and CCDTL with spoke cavity superconducting structure while maintaining possibility for 100 mA future operation.

AAA

Accelerator-Driven Test Facility:

Design of the Target & Materials Test and the Sub-Critical Multiplier and Interim Accelerator Interface Requirements

Design Team: LANL, ANL, BREI, GA

Los Alamos, NM
April 10, 2001

AAA

Outline

- Report to Congress:
  - ADTF Missions
  - Design Configuration
- Pre-Conceptual Design Status:
  - Target & Materials Test (TMT)
  - Sub-Critical Multiplier-100 MW (SCM-100)
- Interim Accelerator Interface Requirements
- Conceptual Design Plan

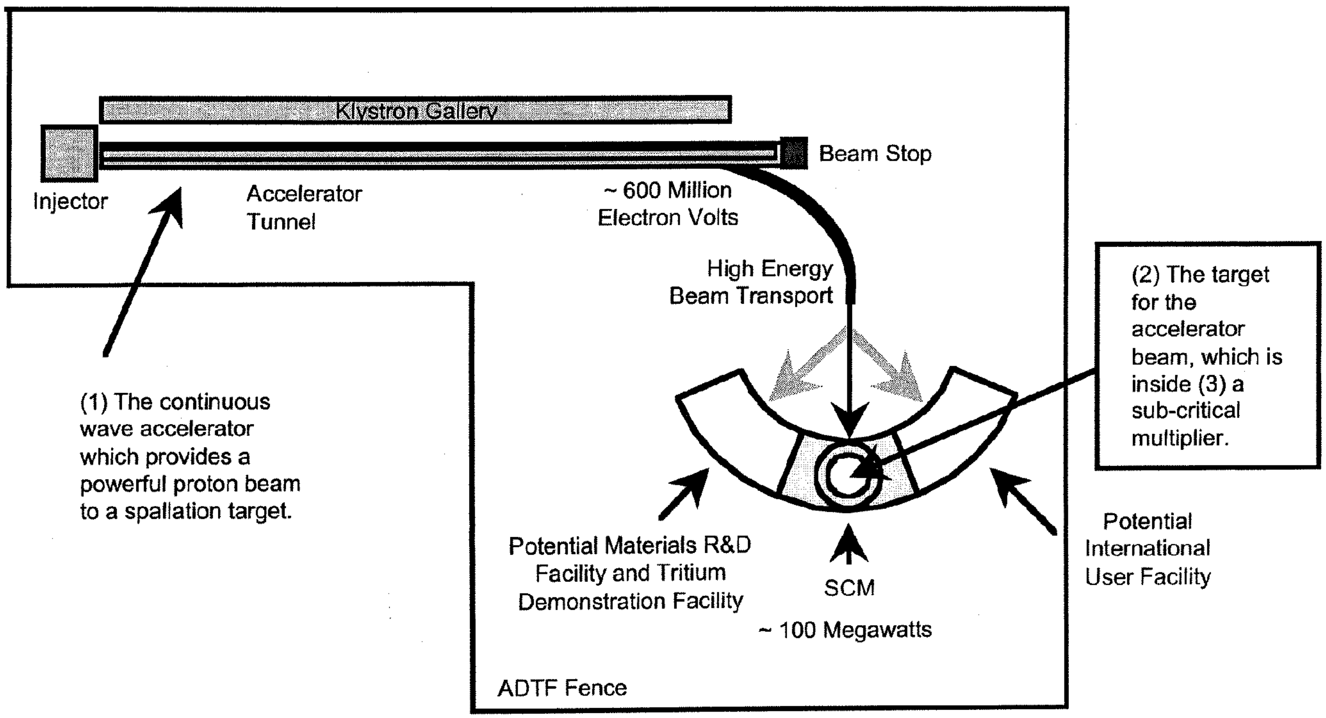
Mission

To meet the objectives of the AAA program, the ADTF provides a world-class accelerator-driven test facility to:

- Provide the capability to assess technology options for the transmutation of spent nuclear fuel and waste through a proof-of-performance and proof-of-practicality demonstrations.
- Provide a user facility that allows testing of advanced nuclear technologies and applications, material science and research, experimental physics, and conventional nuclear engineering science applications.
- Provide the capability, through upgrades or additions to the ADTF accelerator, to produce tritium for defense purposes, if required.
- Provide the capability, through upgrades or additions, to produce radioisotopes for medical and commercial purposes.

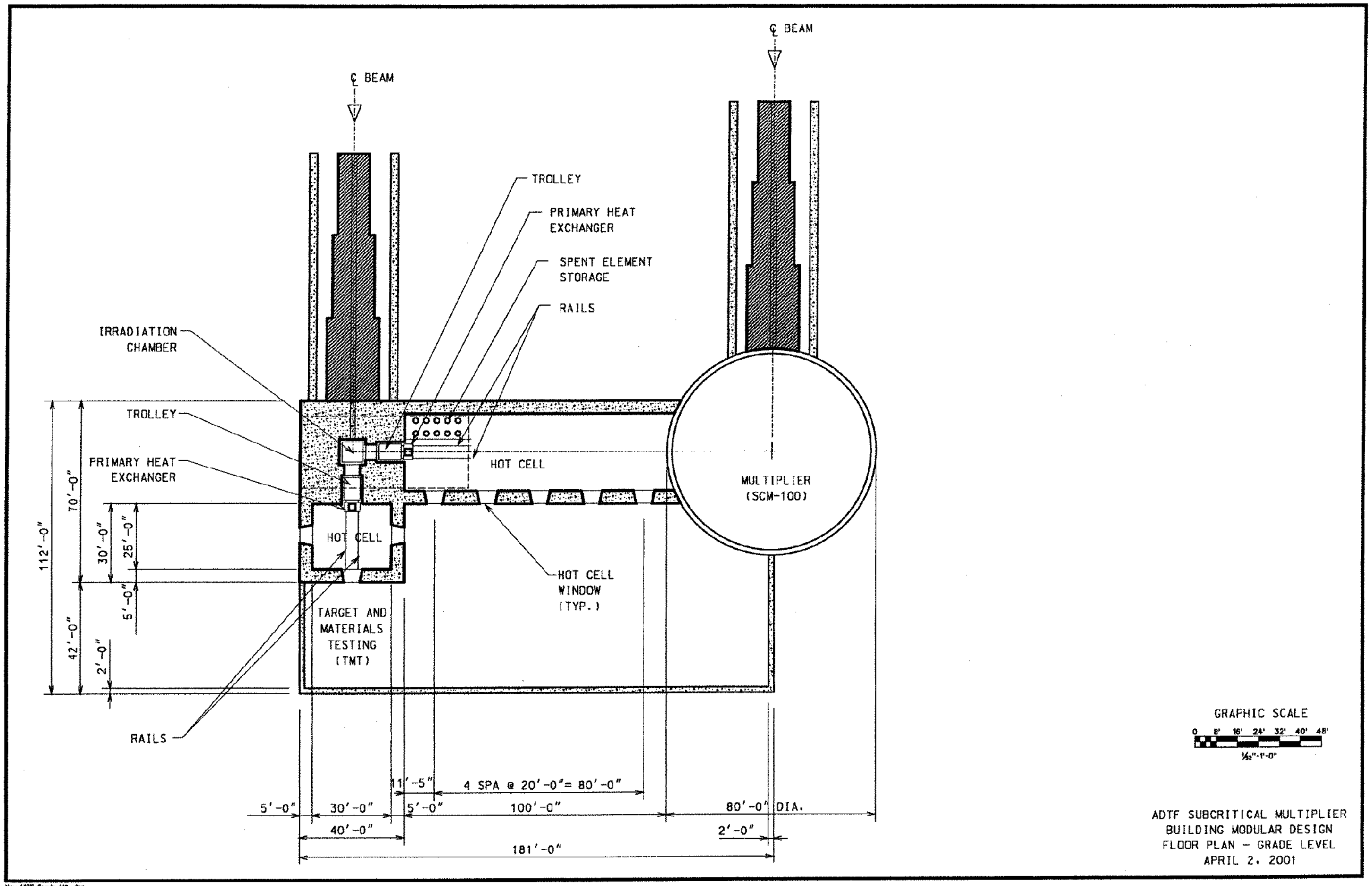
Congressional Report: ADTF Major Elements

Major Elements of the ADTF



In Agreement with the DOE, a Three-Station Design Configuration is Planned

- Initial construction of two target stations
  - Target & Materials Test (TMT)
  - Sub-Critical Multiplier, 100 MW capable (SCM-100)
  - Common hot-cell facilities
- TMT provides test environment for materials and fuel experiments, coolant and target technology, potential to demonstrate tritium production, and the potential for isotope production.
- SCM-100 provides test environment for demonstration of coupling, irradiation of significant quantities of fuel and eventual transition to an actinide core.
- Third target station would be constructed at a later date.


℄ BEAM
℄ BEAM
TROLLEY
PRIMARY HEAT EXCHANGER
SPENT ELEMENT STORAGE
RAILS
IRRADIATION CHAMBER
TROLLEY
PRIMARY HEAT EXCHANGER
HOT CELL
HOT CELL
MULTIPLIER (SCM-100)
HOT CELL WINDOW (TYP.)
TARGET AND MATERIALS TESTING (TMT)
RAILS
112'-0"
70'-0"
30'-0"
25'-0"
5'-0"
42'-0"
2'-0"
11'-5"
4 SPA @ 20'-0"= 80'-0"
5'-0"
30'-0"
5'-0"
100'-0"
80'-0" DIA.
40'-0"
2'-0"
181'-0"
GRAPHIC SCALE
0 8' 16' 24' 32' 40' 48'
ADTF SUBCRITICAL MULTIPLIER
BUILDING MODULAR DESIGN
FLOOR PLAN - GRADE LEVEL
APRIL 2, 2001
New-ADTF Grade LVL.dgn

Target & Materials Test Station (TMT)

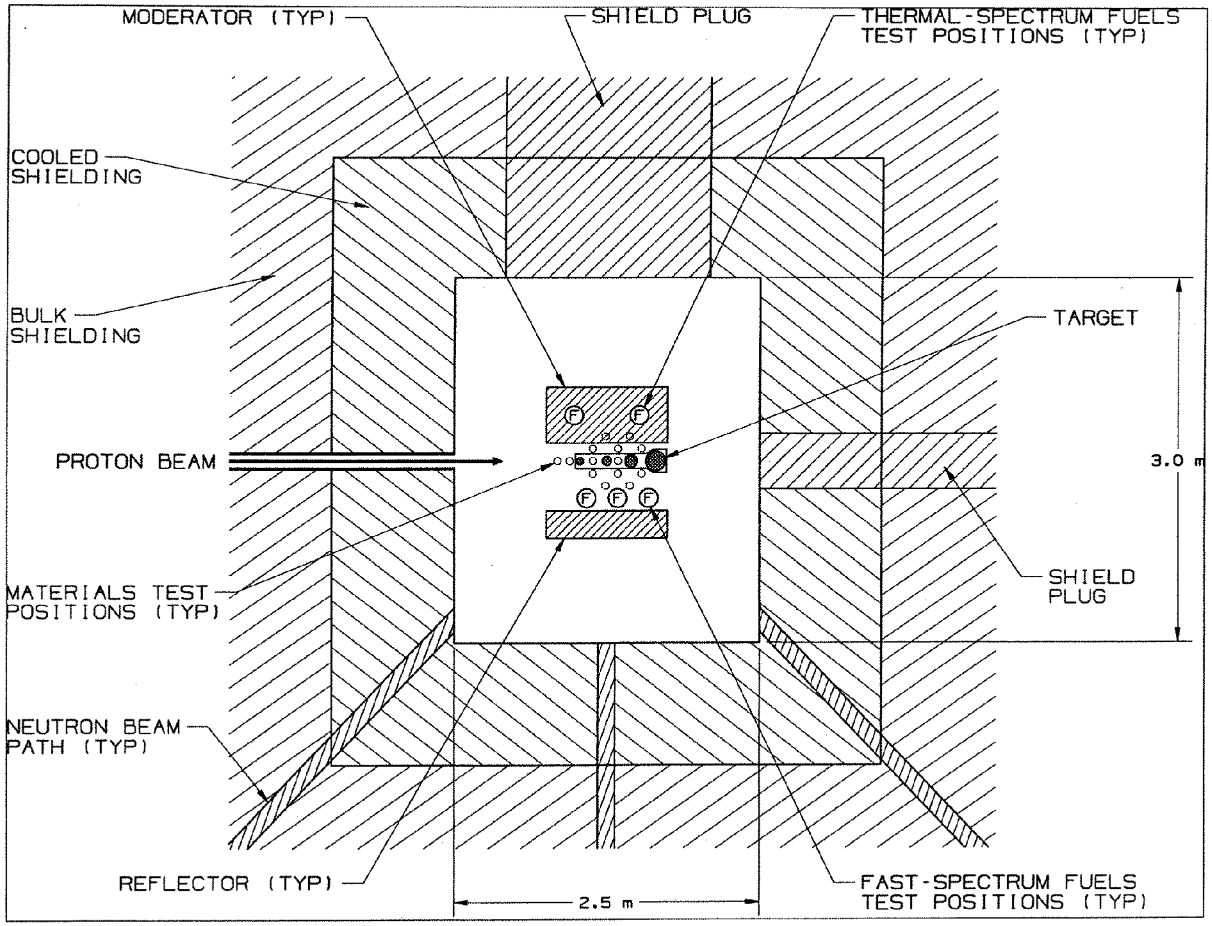
- TMT provides test environment for materials and fuel experiments, coolant and target technology, potential to demonstrate tritium production, and the potential for isotope production.
  - spallation neutron source operate at full beam power (~8 MW)
  - surrounding closed loops for irradiation materials and fuels in different coolant and material/coolant combinations
  - moderated (thermal, epi-thermal) and fast spectrum capability
  - very low multiplication (keff)
  - very low fission power (~2 - 5 MW)

TMT System Characteristics

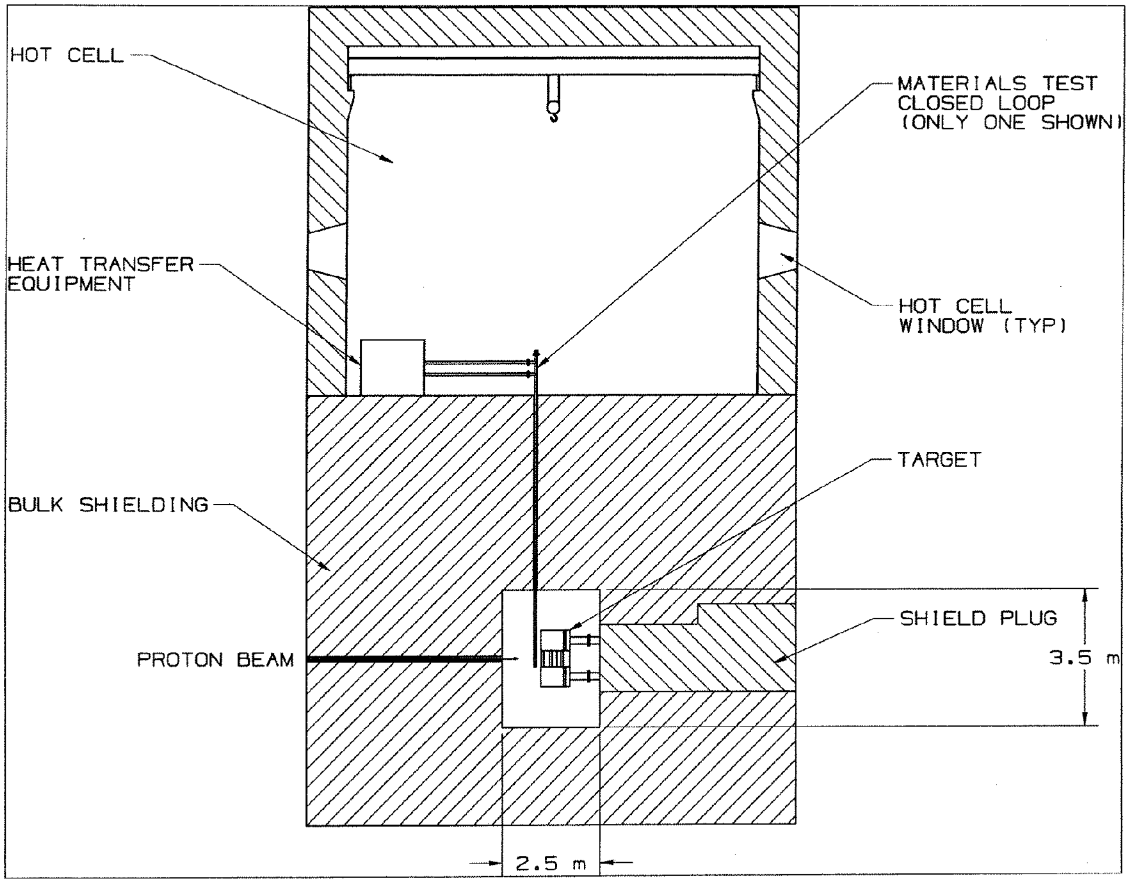
- Horizontal beam insertion into an evacuated experimental chamber
- Horizontal target insertion and replacement (similar to the SNS)
- Horizontal or vertical closed loop insertion
- Hot cells adjacent to the target/multiplier outside shield
- Capability for testing of different target materials and coolants (water-cooled tungsten, helium-cooled tungsten, sodium-cooled tungsten, lead-bismuth)
- Closed loops for testing of small quantities of fuel (10 - 100s of fuel pins or compacts) in either fast or thermal neutron environment and in different coolants.
- Capability for transient testing of fuel
- Capability for irradiating tritium production targets, and isotope production

Plan for initial operation with robust, trip insensitive target will allow for beam commissioning and accelerator reliability demonstration

Plan View of the TMT Experimental Chamber



Elevation View of the TMT Experimental Chamber



Accelerator Interface Requirements Driven by Material Stress Limits and Safety Considerations

- Material stress limits:
  - Beam trips cause coolant temperature excursion which in turn causes the surface temperature on structures to change quickly
  - Causes large transient thermal gradients and high stresses
  - multiple cycles causes fatigue and potential failure
- Safety Considerations
  - Beam overpower (excessive current or energy) potentially cause a power/flow mismatch in the target or multiplier
  - Beam shutdown (i.e.for loss of flow or heat sink)
  - Beam control (current and energy)

Summary of TMT Proton Accelerator Requirements

- The TMT will start operation in approximately year 8 of the schedule
- For years 8 and 9:
  - beam commissioning with full power target that is robust and trip insensitive
- For year 10 and beyond, target and fuel tests will require:
  - Beam current: 1--13.3 mA (cw for operations, pulsed for tune-up and diagnostics)
  - Beam energy: 600 MeV
  - Current stability: ≤ 5 %
  - Safety-class beam shutdown
  - Hard limit on maximum beam current
  - Limit on rate of change of beam current
  - Beam reliability (allowable number of beam trips is TBD, but certainly less stringent than the SCM-100)
  - Ability to smoothly ramp up (or down) beam current (5--100%) over 10 - 20s (for performing fuel transient tests)

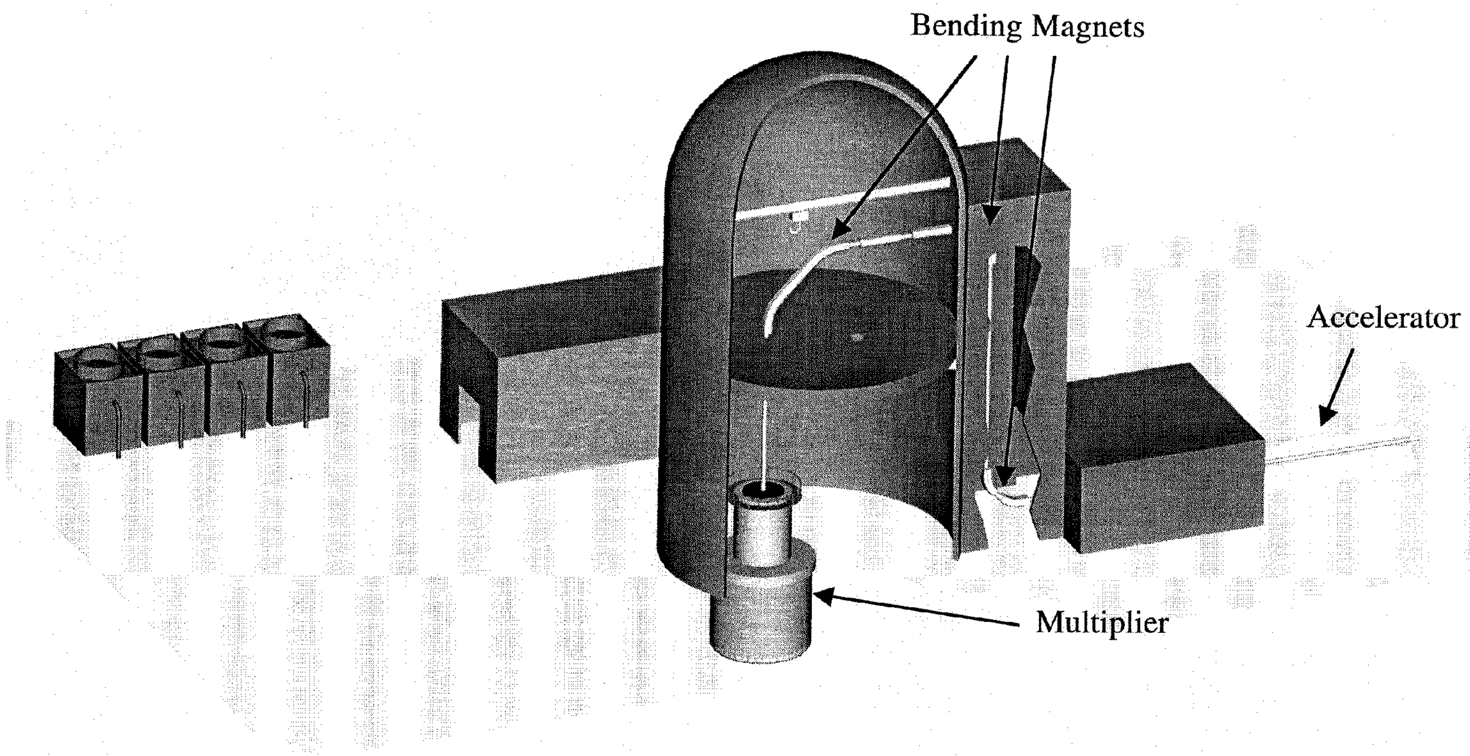
Sub-Critical Multiplier, 100 MW (SCM-100)

- SCM-100 provides test environment for the demonstration of coupling, irradiation of significant quantities of fuel and eventual transition to an actinide core.
  - a large fast spectrum multiplier coupled with a proton accelerator and spallation neutron source
  - demonstration of safe operation and control
  - capability to irradiate large quantities of fuel (40 - 100 kg) for demonstration of transmutation efficiency
  - full scale demonstration of actinide fuels

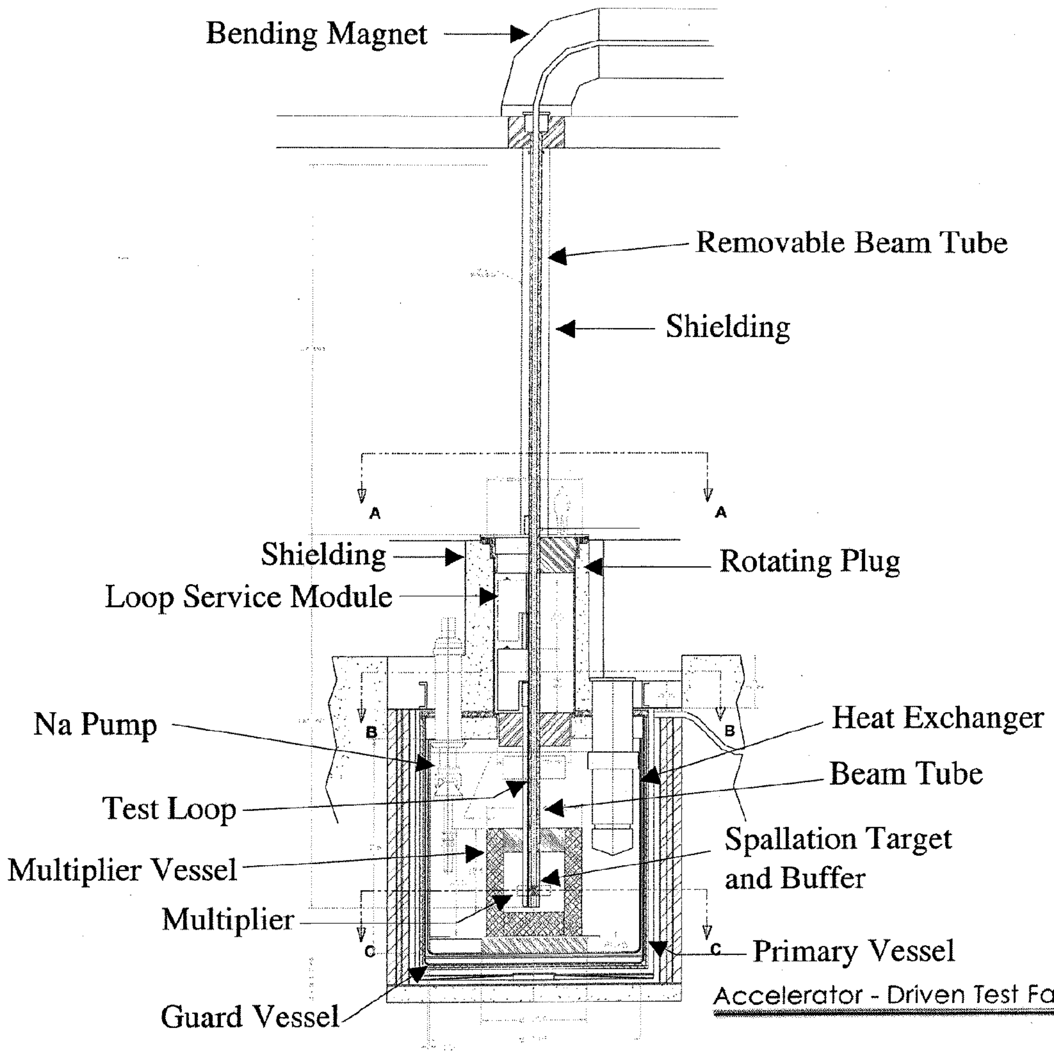
Characteristics of the SCM-100

- Sodium-cooled, pool-type multiplier system using standard U-10%Zr metal fuel, with gradual changeover to prototypic ATW fuel.
- Two primary Na pumps with intermediate heat exchanger to secondary Na system.
- Proven fuel handling using a rotating plug and a rotating offset gripper with transfer to in-vessel storage basket.
- Multiplier 48-in.-diameter (including reflectors) with space for accelerator spallation target/buffer.
- Control rods at periphery or in interior of multiplier fuel region.
- Irradiation assemblies may be placed anywhere in and around the multiplier region and handled same as fuel assemblies, and instrumented assemblies may be included as well, if provisions are initially made for them (i.e., access holes through rotating plug and multiplier vessel cover.)
- Considering both lead-bismuth and sodium-cooled tungsten target. Target will be tested in the TMT.
- Considering both vertical and inclined beam insertion.
- Approach to full power operation will be stepwise (over a year time frame).

SCM-100 Concept with Vertical Entry of Accelerator/Target Tube

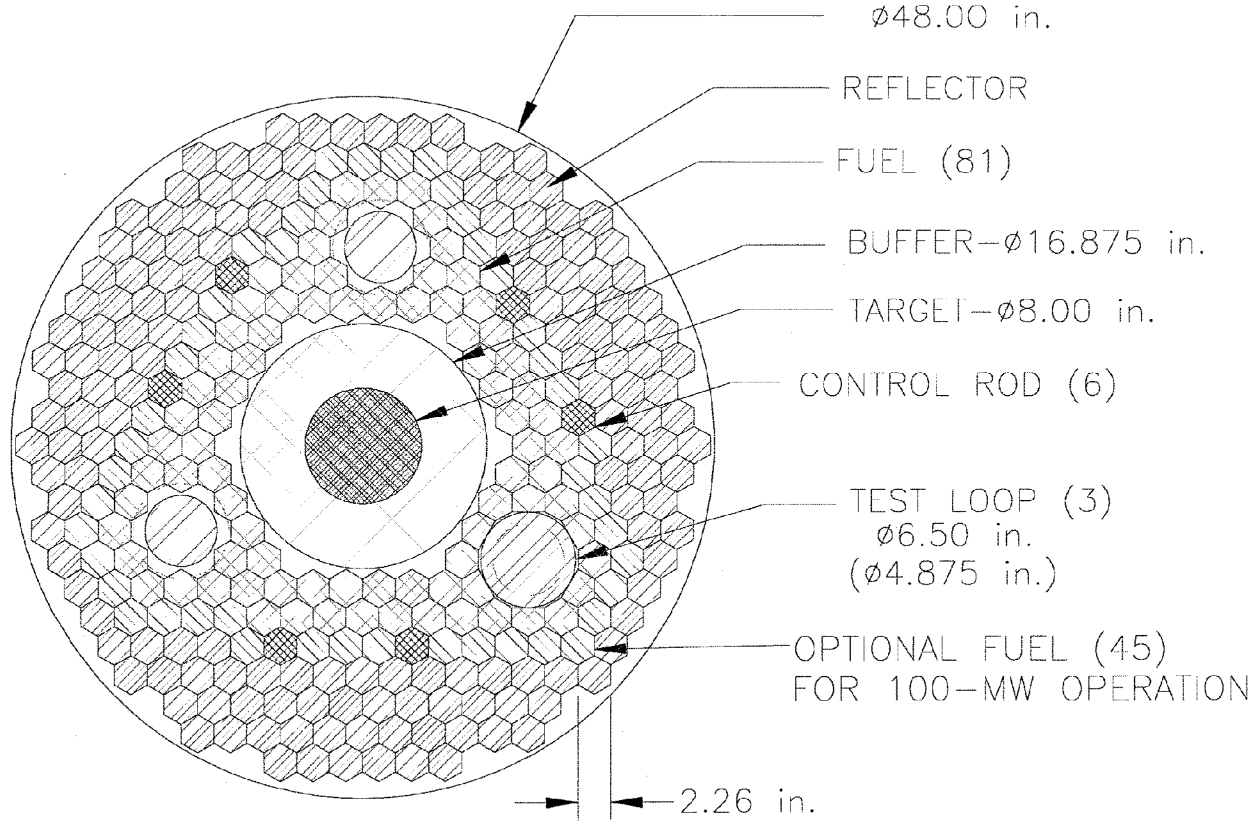


Elevation View of the Vertical-Entry SCM-100



Accelerator - Driven Test Facility ADTF

Target/Multiplier for Vertical-Entry SCM-100

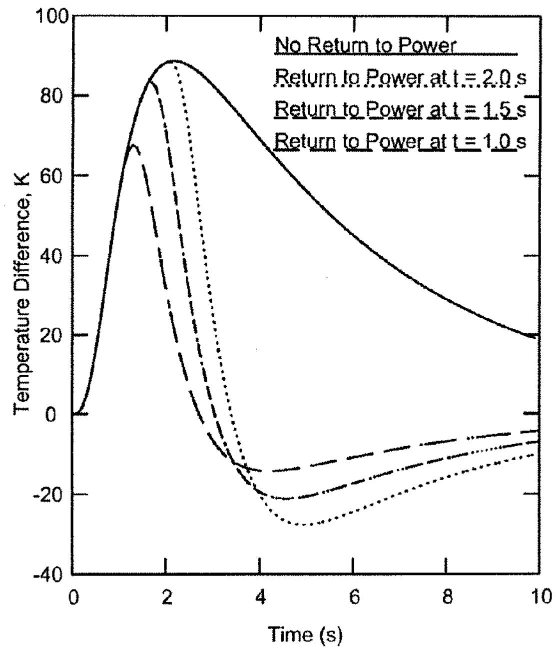


AAA

Structure Fatigue Analysis

- Analyses performed (ANL) for ATW using the Advanced Liquid Metal Reactor design as the basis
  - both sodium and lead-bismuth cooling investigated as well as different steel alloys
  - application of ASME code for fatigue limits
- Analyses initiated for SCM-100. Efforts will be made in the design to reduce sensitivity to thermal transients.

Temperature Transient Example: Sodium-Cooled Reactor System



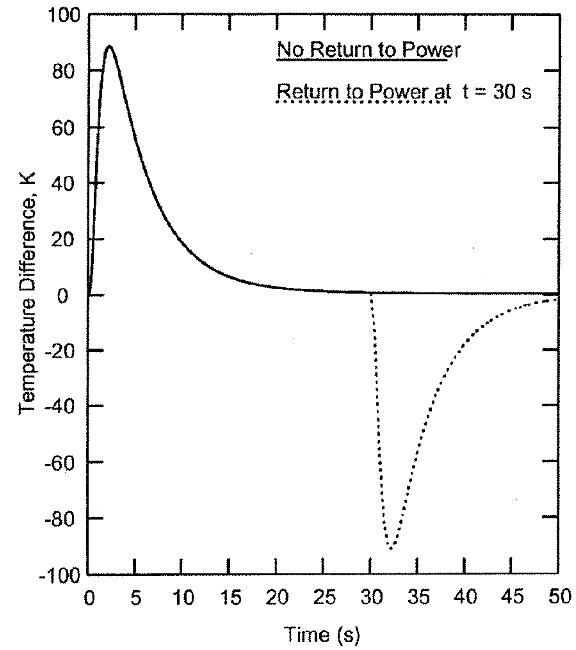


Fig. 16, Influence of Early Return to Power on the Top of Core Difference Between the Structure and the Coolant Temperatures

Fig. 17, Impact of a Sudden Return to Power After Temperatures Have Equilibrated

Estimate of Fatigue Damage sets Allowable Beam Trips

Table 3, Estimates of Fatigue Damage Due to Beam Interruptions

structural element	coolant	material	thickness (m)	peak ΔT (K)	time of peak (s)	allowable cycles	interruptions /year	years of operation
above core load pads	Pb-Bi	martinsitic	.0056495	44.6	3.2	6.8×10^4	14,200	4.8
	Na	HT-9	.0056495	66.2	1.9	7517	14,200	.53
outlet plenum upper wall	Pb-Bi	martinsitic	.0254	27.0	127	1.7×10^5	2019	84+
	Na	304 ss	.0254	40.7	121	10^6+	2019	495+
IHX tube sheet rim	Na	304 ss	.0635	114.3	219	2475	1489	1.7
steam generator tube sheet	Pb-Bi	martensitic	.0753	72.8	191	8100	1551	5.2
	Na	2 1/4 Cr-1 Mo	.0753	68.3	211	2.6×10^5	1489	175

Assuming 4 year fuel bundle life and 30 year IHX life, allowable interruptions per year:

Trip duration	Pb-Bi	Na
2s or more	17,000	1900
3min or more	270	80

From Floyd Dunn

Summary of SCM-100 Accelerator Interface Requirements

AAA

- SCM-100 will start operation approximately in year 11 of the schedule
- Beam current: 1--13.3 mA (cw for operations, pulsed for tune-up and diagnostics)
- Beam energy: 600 MeV nominal maximum
- Current stability: ≤ 1 % *(5% bad, 2% a concern, 1% OK)*
- Safety-class beam shutdown
- Hard limit on maximum beam current and limit on rate of change
- Low incidence of beam trips (based on analysis to date, including margin)
  - 0.3 < t < 100 s   < 1000 trips/yr
  - t > 100 s   < 30 trips/yr
- Active current control: automatic, independent-feedback, dynamic current-control mechanism.
  - Beam-current control must be taken from power monitors.
- Must have ability to smoothly ramp up (or down) beam current (5--100%) over 10-30 minutes
- Availability during run cycle: 85% (plan for 3 x 100 day cycles per year)

AAA

Efforts to Reduce the Sensitivity to Beam Trips will be made during Conceptual Design

Potential Study Areas:

Limit temperature excursions

- Change relative dimensions of support structures (i.e. Intermediate Heat Exchanger tube sheet)
- Increase coolant flow rates (lower delta-T)
- Provide immediate reduction in coolant flow when beam trips
- Use variable-speed primary coolant pump

Control rate of temperature change

- Use programmed, and well-controlled, beam restart
- Use increased volume and/or flow rate of coolant
- Use predictive beam shut off

Use substitute materials and modified geometry

- Design for robustness
- Make design modifications that facilitate a simplified replacement of T/M components.

Summary

- TMT and SCM-100 should meet ADTF missions.
- Design and analysis of systems continuing.
- Initial estimate of accelerator interface requirements provided.
- Initial operation of TMT with robust target design will provide opportunity for accelerator commissioning and reliability demonstration.
- Efforts will be made during conceptual design to reduce beam trip sensitivity.

AAA

A preliminary summary of issues pertaining to the interface between the accelerator and target/multiplier on the ADTF

¥ ADTF Accelerator Requirements

¥ Steps to Improve Accelerator Reliability

¥ Design Mods to Reduce T/M Sensitivity to Beam Trips

by J. David Schneider, AAA-TPO

April 10, 2001

Partial list of Participants and Contributors

- George Lawrence, LANL, *retired*
- Dean Pedersen, ANL
- Mike Cappiello, LANL
- Jim Cahalan, ANL
- Kemal Pasamehmetoglu, LANL
- Joe Herceg, ANL
- Rich Sheffield, LANL
- Floyd Dunn, ANL

Basic Challenge for Interfacing Accelerator and Reactor

AAA

- ¥ Reactor designers view the accelerator as a black box, whose purpose is to provide (on demand) an external source of neutrons with no interruptions. But, all the conventional components of a reactor must be retained, including the control rods, safety requirements, basic configuration, and operating philosophy.
- ¥ By contrast, the accelerator folks tend to view the T/M as a modified, special-purpose beam target with a life of its own, that should be insensitive to beam trips.
- ¥ The myopic view would require either that the accelerator be upgraded to live in the reactor world; or that the reactor must adapt to accept the erratic beam from the accelerator.
- ¥ Our task is to find the best compromise between these two extremes.

AAA

There exists a large difference between T/M beam reliability requirements and present accelerator performance.

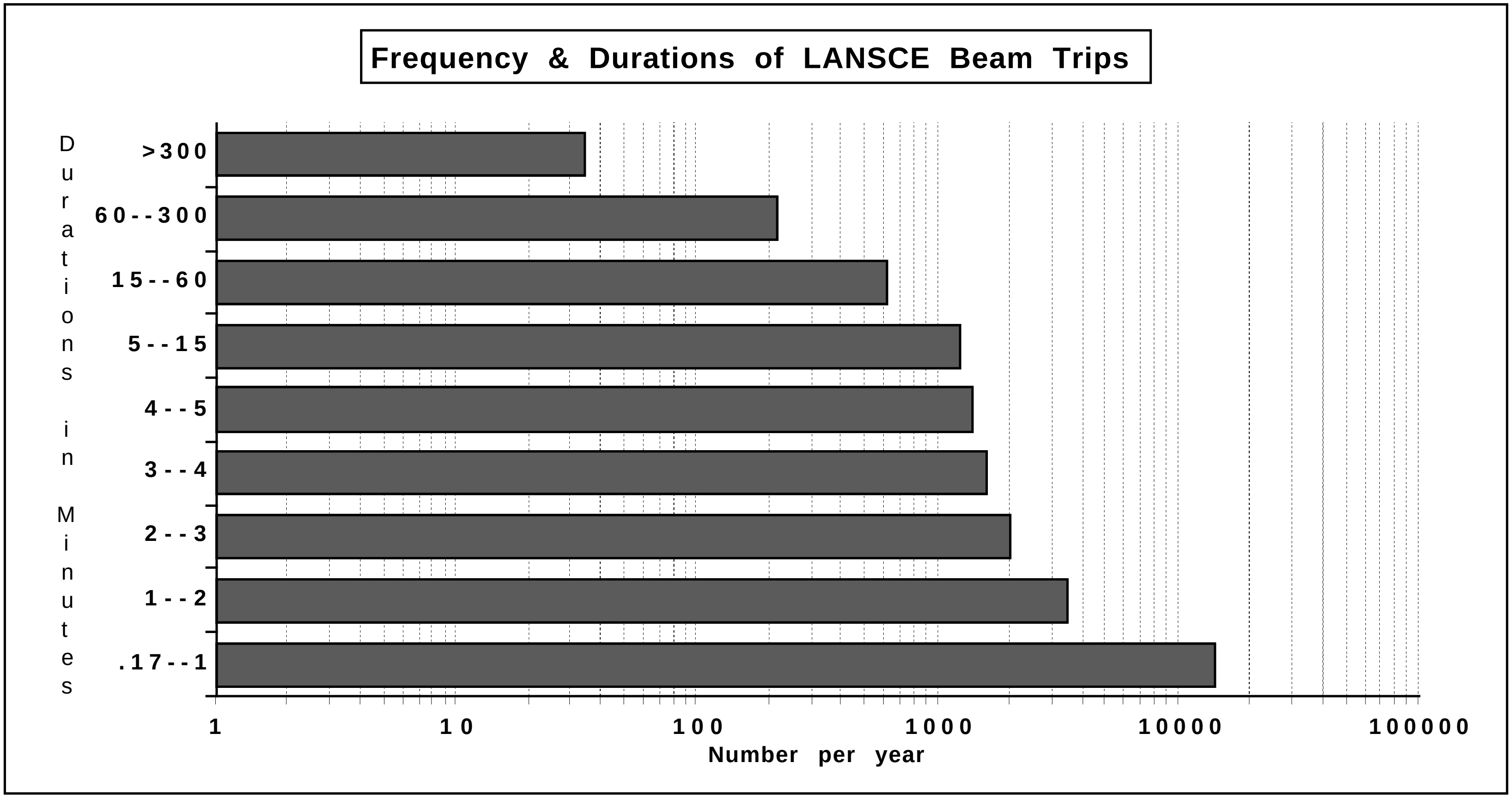
- Basic challenge with respect to beam trips:
  - There is about four orders of magnitude difference between the annual trip rates in commercial power reactors and demonstrated accelerator performance.
- Thermal cyclic fatigue of reactor structures limits the allowable number of thermal cycles.
  - The temperature excursion and rate of temperature change impact the damage per thermal cycle.
- This disparity between reactor needs and accelerator performance can be addressed by improving accelerator reliability and/or by making the reactor less sensitive to beam trips.
  - We can do part of this immediately
  - Full correction will require multiple iterations and more time.

Reducing Beam Interrupts is a New and Challenging Requirement for High-Power Accelerators

AAA

- Existing (LANSCE, PSI) high-power accelerators have approximately 1 - 2 beam interrupts per hour, with durations of 1 second or greater.
- ¥ There are also an unknown number of very short beam interrupts; typically not logged if < 1 second duration.
- ¥ In these machines, the design has given higher priority to equipment protection and overall availability than interrupt-free operation.
- ¥ New linac designs (APT, SNS) have emphasized high availability, but again, interrupt minimization has not been a requirement.
- ¥ ATW systems require drastic reduction in beam interrupt rate so that:
  — damage totransmuters from thermal cycling will be low enough to achieve practical component lifetimes

Number and Durations of Beam Trips at LANSCE



Note. These data are from Marcus Eriksson's thesis, based on the 1996--1997 LANSCE operation, for a non-optimized accelerator, of a 35-year-old design.

How to move the two incompatible systems closer together?

AAA

- Improve operational reliability of the accelerator
  - Modify designs
  - Change operating procedures
  - Use predictive maintenance
- Identify means of making the ADTF T/M less sensitive to beam trips.
  - Gives ability to tolerate more total trips
  - Replace many abrupt trips with slow power ramp down

We cannot expect immediate closure of the four orders of magnitude reliability disparity between the accelerator and target/multiplier.

- Existing accelerator designs probably won t meet the reliability needs of the existing reactor (SCM) designs.
- Conversely, the existing reactor structures may fail prematurely if interfaced with an existing trip-prone accelerator.
- For ADTF to be successful, we must modify designs of both accelerator and T/M.
- In addition, we can expect to change-out several ADTF developmental components after a few-year lifetime.

We can identify several immediate steps to improve accelerator reliability

- ¥ Replace components that are shown to be unreliable
- ¥ Upgrade several high-voltage subsystems (injector, RF power supplies,   )
- ¥ Incorporate more burn-in operation
- ¥ Back off from maximum levels
  - — Reduced currents (<<100 mA) will help significantly
  - — More power margin on klystrons, power supplies, & other systems
- ¥ Incorporate more 24/7 operation
- ¥ Use sensors and computers to predict component failures
- ¥ Use some selected installed redundancy
- ¥ Incorporate fast cavity re-tuning and compensation for failed accelerating units (SC only)

Expectations on improving accelerator reliability

¥ LANL tests indicate promise of very long RF window lifetimes

¥ We need more operational data on support and utility systems

¥ Currently, LEDA has large numbers of trips due to false positives on the instrumentation and protection systems.

¥ We have good prospects for getting rapid recovery from beam trips; many can be restored in less than 300 s, most within 200 ms.

¥ Beam-power trips of less than about 300 ms should cause only negligible thermal stresses within the Na-cooled reactor.

¥ Computers and control systems will need improvements in robustness.

¥ Indications are excellent on injector; reliability improves with run time.

¥ Several minor improvements are needed on the LEDA RF power systems. For ADTF, dramatic improvements appear feasible.

Expectations on accelerator reliability improvements

- Can expect immediate improvement of perhaps an order of magnitude over LANSCE technology. Achieving more than one order of magnitude likely will require more than a single generation of upgrades.
- We must have much more run time to generate reliability statistics on new and relevant accelerator designs, such as LEDA.
- Also, to improve statistics and success rate, we should operate beam through more accelerating structures and with more equipment in place.
- Increased, sustained ADTF beam commissioning with the robust target should get us past most accelerator-component infant mortality.

Procedures for Improving Accelerator Reliability

- ¥ Minimize the total number (frequency) of unscheduled beam trips.
- ¥ Design modifications should permit riding through (without tripping) a good fraction of minor faults.
- ¥ Sustained operation will automatically improve reliability.
- ¥ Minimize operational diagnostics. Improve the functioning of the remainder. Objective is to reduce the number of false positives on equipment faults.
- ¥ Running sub-systems at operational levels well below design max points will improve reliability.
- ¥ Replace most-troublesome or fault-prone components with modern, reliable designs.
- ¥ Burn-in or conditioning.
- ¥ Gradual build up to operating power levels
- ¥ Use of some installed redundancy

Develop improved failure predictive capability.

- ¥ We must accept the fact that accelerator trips will not be reduced to zero. However, if we can identify an operational scenario where the great majority of beam interrupts are planned and infrequent, then T/M damage or disturbances will be minimized. For these planned outages, a very gradual and controlled beam power (current) rampdown and rampup are essential. Slow changes in T/M power level (temperatures) will minimize the materials stress for each interruption and thus extend the T/M lifetime.
- ¥ The number of planned beam interrupts should be reduced significantly if we have a successful method for predicting component failures. Prediction can be enhanced if we are able to monitor performance and thus predict impending failure with good probability. Conducting most repairs and/or replacements in parallel during scheduled shutdown periods will minimize both the number and durations of all beam interruptions.

Candidate steps to improve injector reliability

Increase source lifetime

¥ Replace the ion-source microwave feed with circular polarizer
  — Cuts source power requirements by 2X
  — Eliminates the present microwave window

Reduce high-voltage faults

¥ Replace present extractor HV insulator with a Kofoid geometry.
  — Permits use of single and smaller insulator
  — Might give 8-fold voltage holdoff improvement
¥ Isolate outside of HV insulator from dirty air environment
¥ Possible reduction of injection energy.
  — Reduces number of high-voltage related beam trips
  — Reduces length, cost, and power losses of RFQ
  — Requires RFQ rebuild

ADTF will require smoothly variable beam currents.

¥ We need to demonstrate an effective means of smoothly adjusting the beam current. Possible methods include:
  — A method for changing the extractor gap during beam operations.
  — Incorporation of a full-power variable iris to control the beam admitted into the RFQ.
  — Possible incorporation of intermediate and variable-voltage electrodes in extractor gap.

¥ We also must have an automatic, independent-feedback, dynamic current-control mechanism.
  — Beam-current control must be taken from fission-neutron fluence monitors.

New Approach to Accelerator Design can Dramatically Reduce Frequency and Length of Beam Interrupts

- **Objectives for ATW plant accelerator design:**
  - —reduce number of visible († 0.3 sec) interrupts to < 1000/year
  - —reduce number of long-duration (‡ 100 sec) interrupts to < 30/year
  - —can we do it; what are the nominal design approaches?

¥ **Basic characteristics that should be included in accelerator design:**

- —fault tolerance of linac with respect to individual accelerating modules and focusing elements.
- —capability for rapid retuning (< 100 ms) following a fault.
- —redundancy for limited-life components and subsystems.
- —design and operation in conservative parameter space (voltages, power densities, thermal management, etc.).
- —reduction in total number of components, where possible.
- —diagnostics to provide advance warning of component failures.

¥ **The use of superconducting RF accelerating cavities has significant advantages for a high-reliability design.**

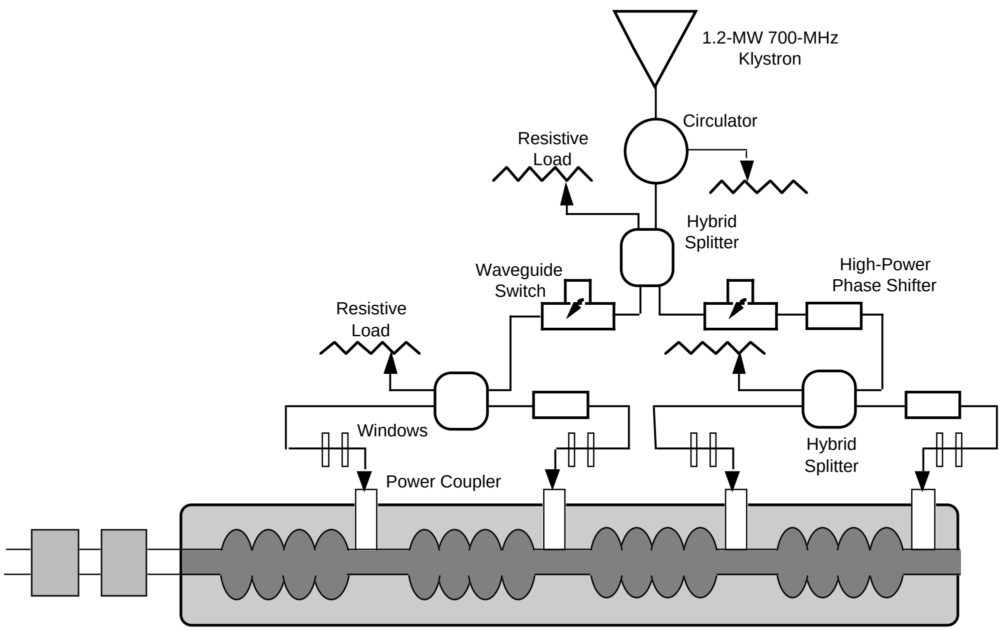
Beam Dynamics Error Studies for APT Linac Show that Fault Tolerant Design is Attainable

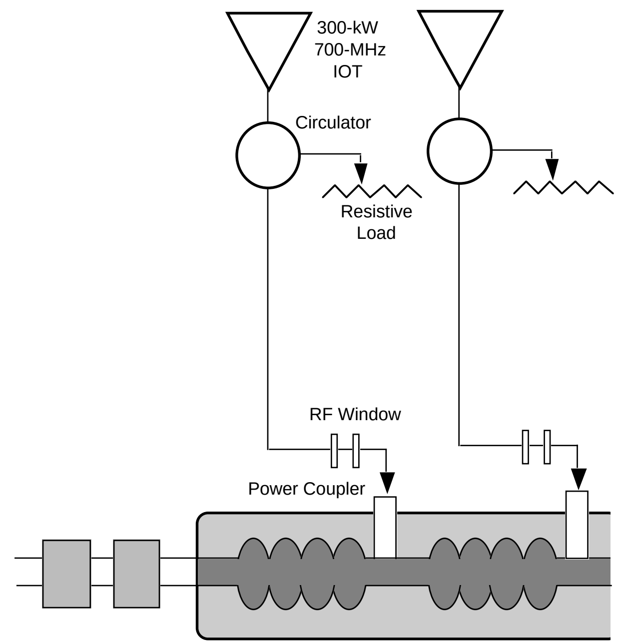
- Simulations showed we can operate the SC linac without beam loss with:
  — any single cavity failure.
  — any single klystron failure (all cavities in rf module).
  — any single quadrupole magnet failure.
  — any single cryostat failure (all cavities and magnets).
- Phases of cavities downstream of failed cavities are reset after cavity or klystron failures. And, the failed cavity must be detuned.
- Operation with failed cavities and klystrons is compensated by extra 5% of RF power installed.

RF System Architecture Can be Optimized for Lower Cost or Higher Reliability but not Both

Minimum cost RF system
- high-power generators
- multiple cavity feeds per tube

High-reliability RF system
- medium-power generators
- one cavity per tube





AAA

Components and Subsystems Should be Designed to Operate in a Conservative Regime

Injector

— LANSCE operations data show that 750-kV Cockroft-Walton injector is major source of beam interrupts. ATW will use a modern 75 kV injector.
— experience with SILHI at Saclay indicates that beam interrupt rate goes to zero when current is decreased to 80 mA (20%below maximum)

SC accelerating cavities

— experience at Jefferson Lab. shows that cavity arc rate goes from 50 per shift to 0.2 per shift when E_oT is decreased 5% from maximum

RF power system

— lower-power klystrons to allow lower HVDC power supply voltages
  — specify, burn-in klystrons to 150% of rated power to minimize gun arcs, internal RF arcs, output window arcs, thermal degradation
  — specify, test RF cavity windows at 5 x rating to eliminate failures
  — specify, test circulators & loads to 2 x rating to eliminate failures
  — minimize noise in protection circuits; eliminate most false RF trips

¥ Total benefit from using these design rules could be more than one order of magnitude reduction in beam interrupt rate.

¥ Tradeoff will be increased cost of accelerator

Conclusions
(from George Lawrence)

- ¥ Goals for high-reliability ATW accelerator design: reduce beam interrupts † 0.3 sec by up to 2 orders of magnitude; reduce beam interrupts ‡ 100 sec to less than 30 per year.
- ¥ Design approach incorporates high fault tolerance, rapid retuning, component redundancy, and conservative parameters.
- ¥ Cost increases for this reliability engineering may be significant.
- ¥ A superconducting linac design provides significant advantages for achieving this goal.
- ¥ New techniques should be demonstrated that involve rapid automatic retuning of cavities or focusing magnets after a fault while beam is on. R&D in this and other areas is essential. ADTF can be a test bed.
- ¥ A goal of reducing beam interrupts by 2 orders of magnitude is challenging, but we are optimistic that it can be achieved using the design principles outlined here.

AAA

Design modifications to the Target/Multiplier can reduce the T/M susceptibility to beam trips

Limit temperature excursions

- ¥ Change relative dimensions of support structures
- ¥ Increase coolant flow rates
- ¥ Provide immediate reduction in coolant flow when beam trips
- ¥ Use variable-speed primary coolant pump

Control rate of temperature change

- ¥ Use programmed, and well-controlled, beam restart
- ¥ Use increased volume and/or flow rate of coolant
- ¥ Use predictive beam shut off

Use substitute materials and modified geometry

- ¥ Design for robustness, not efficiency
- ¥ Make design modifications that facilitate a simplified replacement of T/M components.

Implications for ADTF Design

- Initial ADTF accelerator commissioning should be done with a trip-insensitive target.
- The multi-year commissioning phase should result in a much-improved operational reliability.
- Eventually, ADTF must show feasibility of an ATW production facility.
- The prototypic (100-MW) multiplier (SCM) will be brought to full power slowly (over several years).
- Some design modifications to the T/M will make it less sensitive to beam trips; easily compatible with the now improved-reliability accelerator.

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 — 12, 2001

Schedule

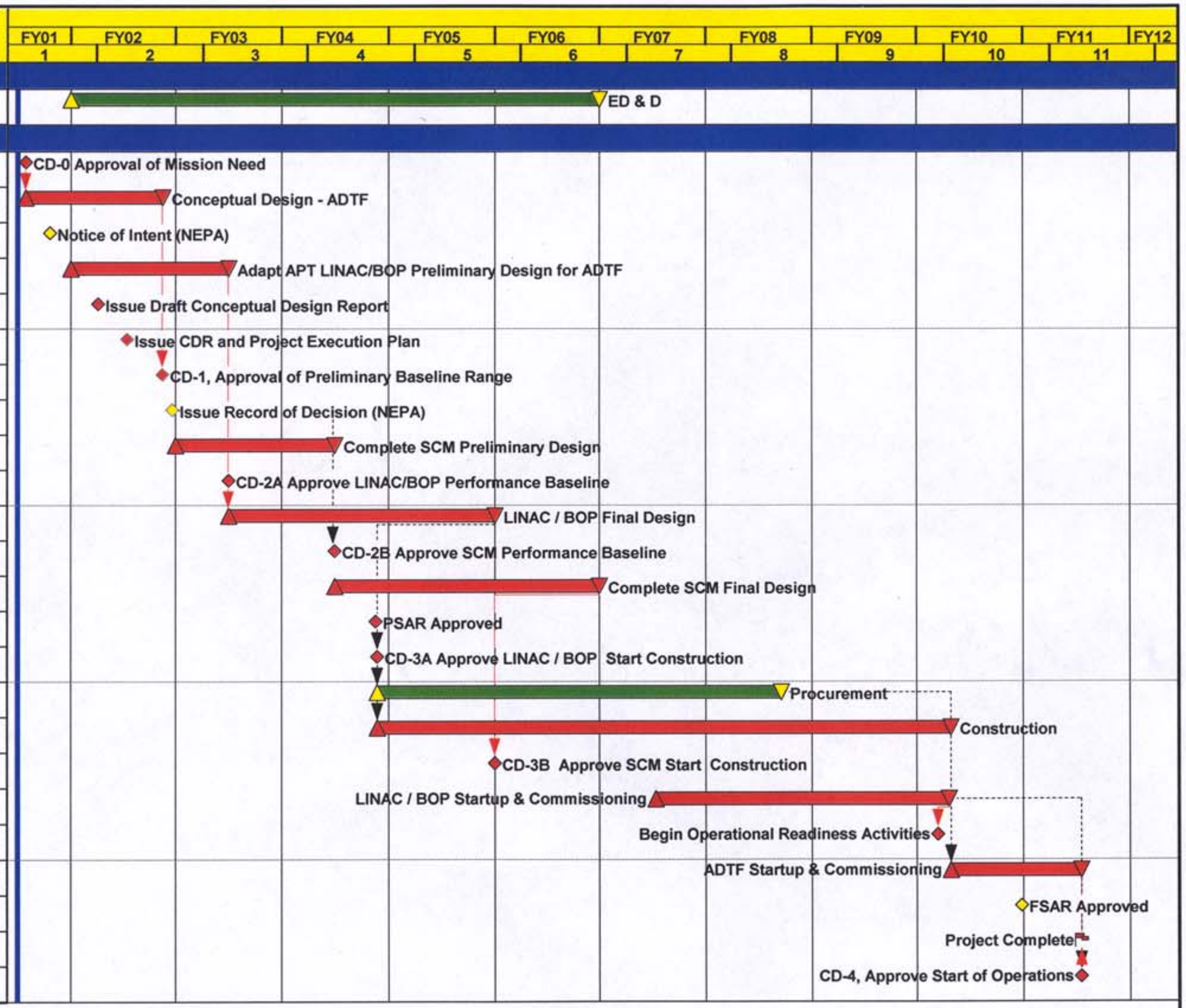
Steve McConnell

AAA

AAA Programmatic Goal requires an operational facility within a 10 year period

- Preconceptual Schedule Range has been developed consistent with this goal; major assumptions include
  - —Funding profile in outyears consistent with budget request ($85M in FY02)
  - —Transition the APT linac design and advance key ED&D activities in FY02 to allow final design to commence in FY03
  - —Start Construction and some long-lead procurements as early as FY04
  - —Accelerator Maintenance Building available for receipt and pre-installation checkout of linac components in FY06
  - —Phased startup and testing integrated with construction sequence to allow testing to commence in FY07
  - —Commence integrated system testing on target in FY10
- Conceptual design will focus on and further develop multiple station approach

Activity ID	Orig Dur	Early Start	Early Finish	Activity
ENGINEERING DESIGN & DEVELOPMENT				
ADTF01730	1,230	01OCT01*	29SEP06	ED & D
1.20 ACCELERATOR DRIVEN TEST FACILITY				
ADTFM1001	0	02MAY01*		CD-0 Approval of Mission Need
ADTF00881	319*	02MAY01	14AUG02	Conceptual Design - ADTF
ADTF00771	0		23JUL01	Notice of Intent (NEPA)
ADTF01600	365	01OCT01	01APR03	Adapt APT LINAC/BOP Preliminary Design for ADTF
ADTF00471	0		07JAN02	Issue Draft Conceptual Design Report
ADTF00561	0		15APR02*	Issue CDR and Project Execution Plan
ADTFM4004	0		14AUG02	CD-1, Approval of Preliminary Baseline Range
ADTF00441	0		19SEP02*	Issue Record of Decision (NEPA)
ADTF01080	363	01OCT02	29MAR04	Complete SCM Preliminary Design
ADTF01280	0	02APR03		CD-2A Approve LINAC/BOP Performance Baseline
ADTF01590	621	02APR03	03OCT05	LINAC / BOP Final Design
ADTF01250	0		29MAR04	CD-2B Approve SCM Performance Baseline
ADTF01260	621	30MAR04	29SEP06	Complete SCM Final Design
ADTF01360	0		20AUG04	PSAR Approved
ADTF01670	0		23AUG04	CD-3A Approve LINAC / BOP Start Construction
ADTF01420	938	24AUG04	18JUN08	Procurement
ADTF01430	1,325*	24AUG04	20JAN10	Construction
ADTF01385	0	03OCT05		CD-3B Approve SCM Start Construction
ADTF01650	682	10APR07	19JAN10	LINAC / BOP Startup & Commissioning
ADTF01500	0	07DEC09		Begin Operational Readiness Activities
ADTF01615	307	21JAN10	18APR11	ADTF Startup & Commissioning
ADTF01525	0		24SEP10	FSAR Approved
ADTF01555	0		18APR11	Project Complete
ADTF01660	0		18APR11*	CD-4, Approve Start of Operations



Start Date	01OCT95	
Finish Date	18APR11	
Data Date	01APR01	
Run Date	10APR01 16:53	

Early Bar
Progress Bar
Critical Activity

1MAR - ADTF

Sheet 1 of 1

ADTF Preliminary Schedule Range

Accelerator - Driven Test Facility ADTF

Additional Accelerator R&D Tasks

On LEDA:

¥ Measure and understand operational reliability

¥ Characterize operation at reduced currents

¥ Add current control

¥ Test first prototypic ADTF accelerating structures

¥ Test T/M required functions: beam-current limit, current control, & safety beam trip.

¥ Prototype 100-MeV CCDTL & high-power test

¥ Plan for integrated testing during ADTF commissioning

Comments by Dave Schneider, AAA-TPO

Demonstrated Beam Performance Summary of the LEDA

- The LEDA injector has demonstrated both pulsed and cw beam operation exceeding 100 mA, with good stability and impressive reliability.
- RFQ operation has demonstrated design current, transmission, and emittance.
- RF power systems and RF windows have delivered design-level performance.
- LEDA has successfully integrated all accelerator-related systems: injector, RFQ, RF, diagnostics, controls, and utilities.
- We thus have high confidence that the basic APT accelerator design will meet ADTF requirements.
- However, we suspect that meeting the T/M reliability needs may be beyond the capability of the existing hardware and/or design. Development and improvements are thus needed on accelerator reliability.

General Reliability Testing and Development Using LEDA

AAA

- Use this existing accelerator to identify the components, systems, and processes that contribute to degrading operational reliability.
- Embark upon a program to correct those items that have the major contribution to degradation of reliability.
- Identify additional and follow-on work and design modifications that offer promise for improving accelerator operational reliability.
- Perform advance planning to support the possible addition and testing of other structures onto the output of the existing LEDA.
- Maintain an active lessons-learned documentation program to capture and utilize the LEDA experience.

T/M functions to install and demonstrate on the LEDA injector:

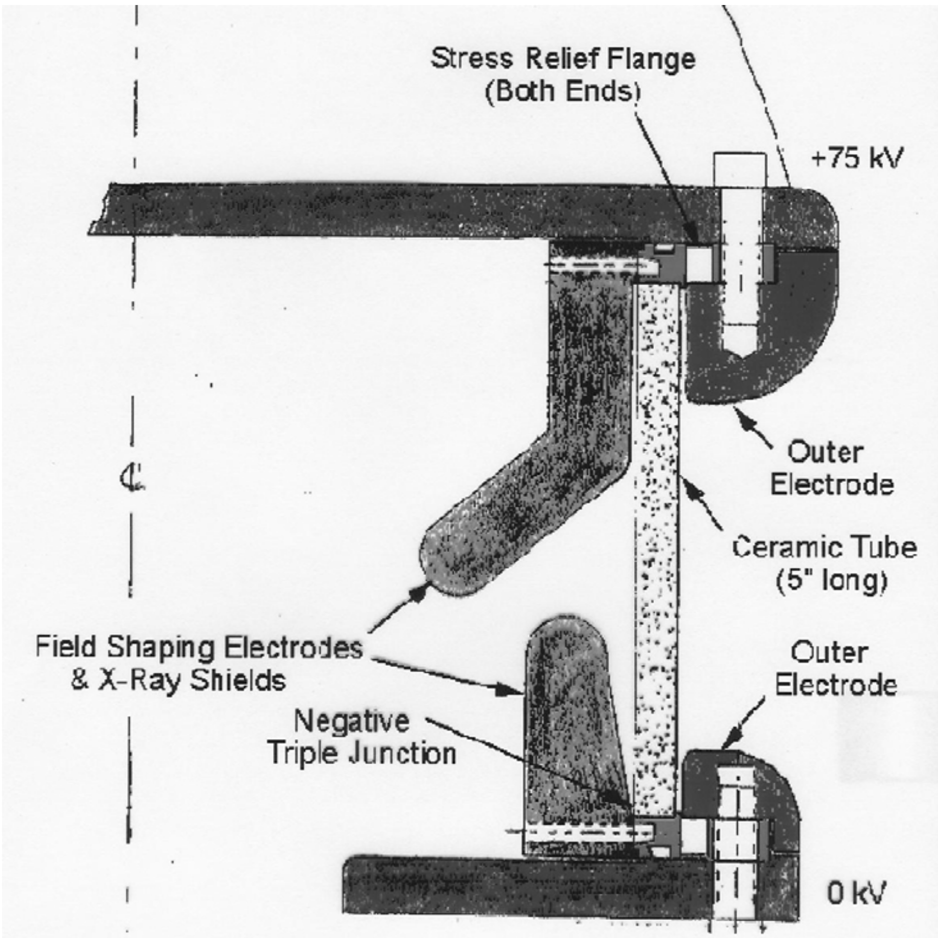
AAA

- A method for providing smooth and precise beam-current control
- Maximum current limit
- Reliable fast recovery from beam interrupts
- Safety-class beam shut off
- Slow and precise beam current rampup
- Beam-current control via direct connection to a robust monitor of T/M power level
- Reduction of beam-current fluctuations

<u>Other Reliability Enhancements</u>

- Ability to predict failures or impending trips
- Operation of a circularly polarized microwave feed
- Beam operation with the Kofoid HV insulator

A preliminary test of the Kofoid geometry confirmed a reduction of the susceptibility of the negative triple junction to sparkdowns.

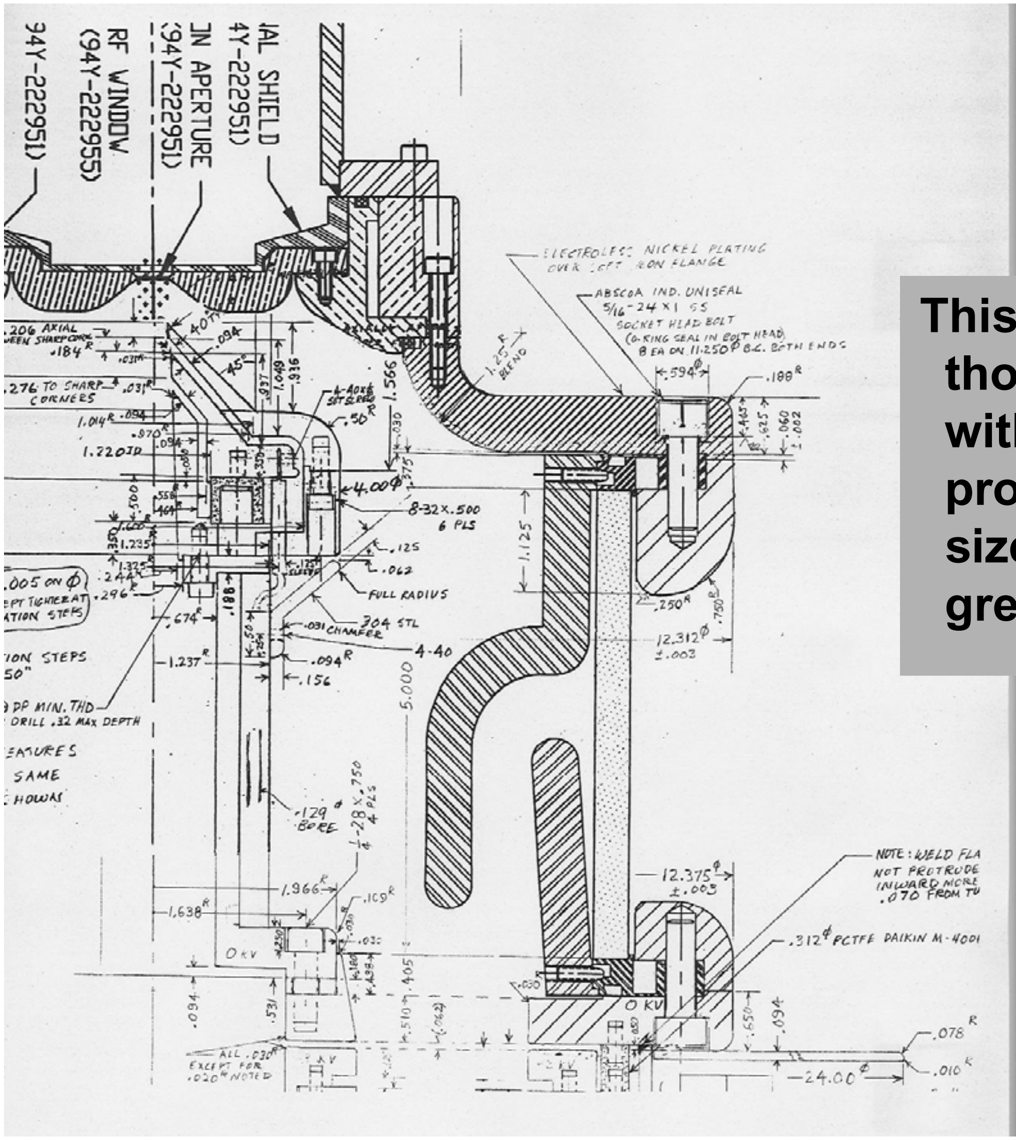


A single reported test of this configuration by Kofoid indicated a 8X improvement in voltage-holdoff capability.

A similar voltage test at LANL confirmed stable operation at our maximum voltage test capability.

Incorporation of this basic geometry on LEDA offers promise of a much lower HV sparkdown rate.

Proposed Kofoid Extractor Geometry



This geometry has been thoroughly analyzed, tested without beam, and offers promise of much smaller size, better gas flow, and greatly improved reliability.

AAA

Reliability tests are needed on several RF power systems.

- Instrumentation sensors and electronics
- RF dummy loads & WG switches
- Cooling system sensors
- Oil tank connectors
- Circulators
- High-voltage power supplies
- RF window vacuum pumps and systems
- Arc sensors
- Klystron degradation, failure modes, maintenance

Development is needed to demonstrate the lower-power, broadcast-technology RF power units for SCRF applications.

AAA

- RF Station Development
  - 10 and 55-kW, 350-MHz systems
  - 100-kW, 700-MHz systems
- Each is an extension of broadcast (410--840-MHz) technology
  - Two are an extension of broadcast power (20--50 kW)
  - 350 MHz is outside the primary frequency band
- Time required:
  - About 1.5 years for equipment delivery, plus
  - About 1 year for checkout and testing

Other critical accelerator reliability studies and enhancements on LEDA

¥ Must do more extended beam runs to get better failure statistics

¥ Incorporate multi-point sensors and use logic to largely eliminate trips from single-point instrumentation failures

¥ Review and improve failure-prone instrumentation

¥ Determine if, and at what rate, RF windows de-condition

¥ Determine what operational diagnostics are most critical

¥ Refine cryopump regeneration processes

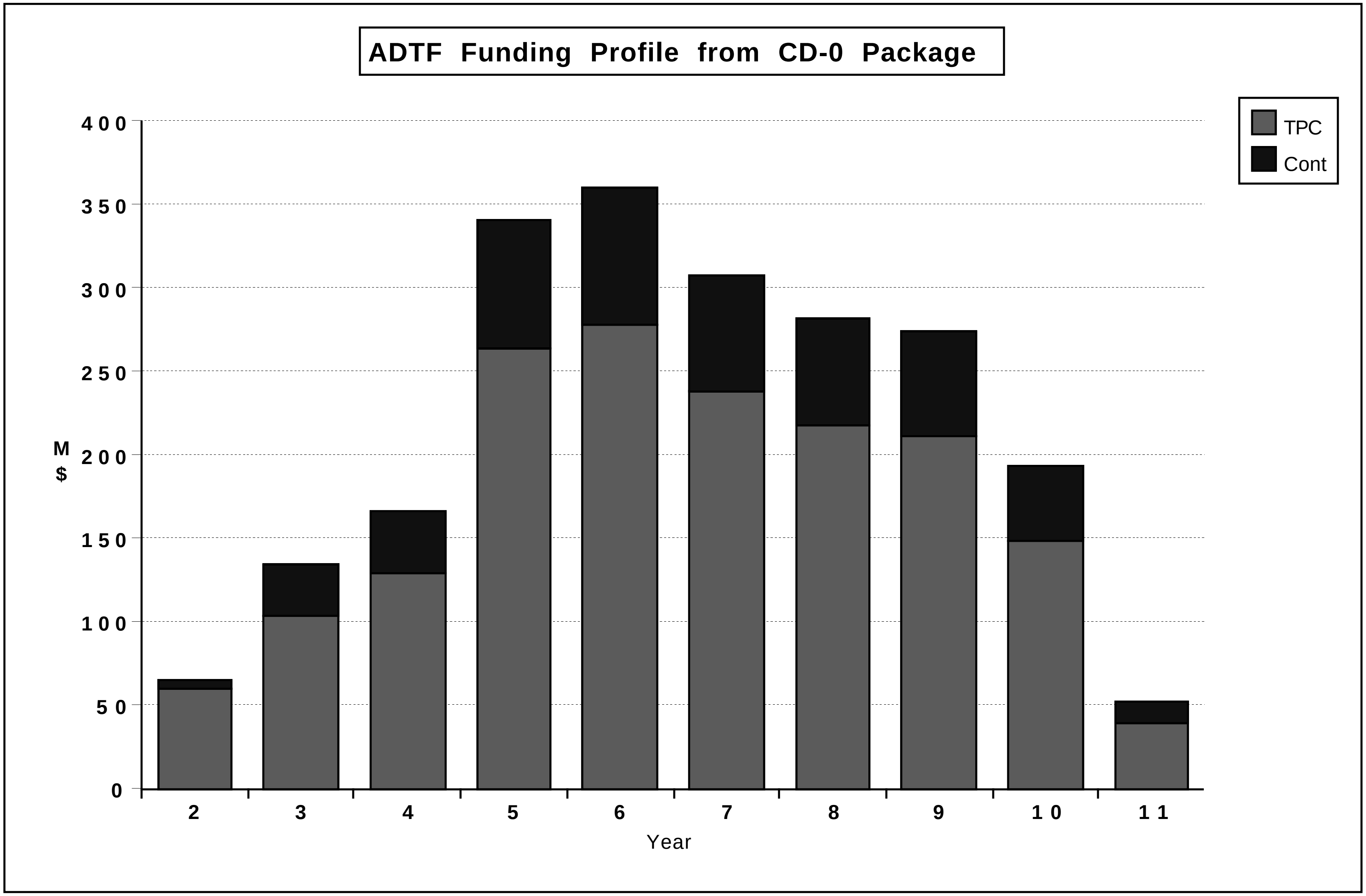
¥ Modify and verify fault reduction of cooling systems

¥ Modify operator interface to alleviate operator-error-induced beam trips

Integrated accelerator development must be done on the ADTF

AAA

- Run extensive beam simulations to model tune-up conditions
- Compare initial pulsed beam with previous simulations
- Vary scores of parameters to establish partial derivatives for later automatic re-tunes
- Tests of de-powering select SCRF cryomodules
- Develop the retune procedure to verify fault-tolerant operation
- Develop and verify beam rampup procedures


ADTF Funding Profile from CD-0 Package
TPC
Cont
400
350
300
250
200
150
100
50
0
M$
2
3
4
5
6
7
8
9
10
11
Year

Key Dates on ADTF Accelerator Schedule

Activity Name	Start Date	Finish Date
Issue CDR & PEP	4/15/02	
Adapt APT PD for ADTF	10/1/01	4/1/03
CD-2A Approve Linac Performance Baseline	4/2/03	
Linac/BOP Final Design	4/2/03	10/3/05
Approve Linac/BOP for Construction, CD-3A	8/4/04	
Procurement	8/24/04	6/18/08
ADTF Construction	8/24/04	1/20/10
Test some ADTF Hardware on LEDA	7/4/05	1/8/07
Linac/BOP Startup & Commissioning	4/10/07	1/19/10
ADTF Startup & Commissioning	1/21/10	4/18/11
Project Complete, Start Operations	4/18/11	

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011

An aggressive procurement of the first modules of the ADTF low-energy linac offers many advantages.

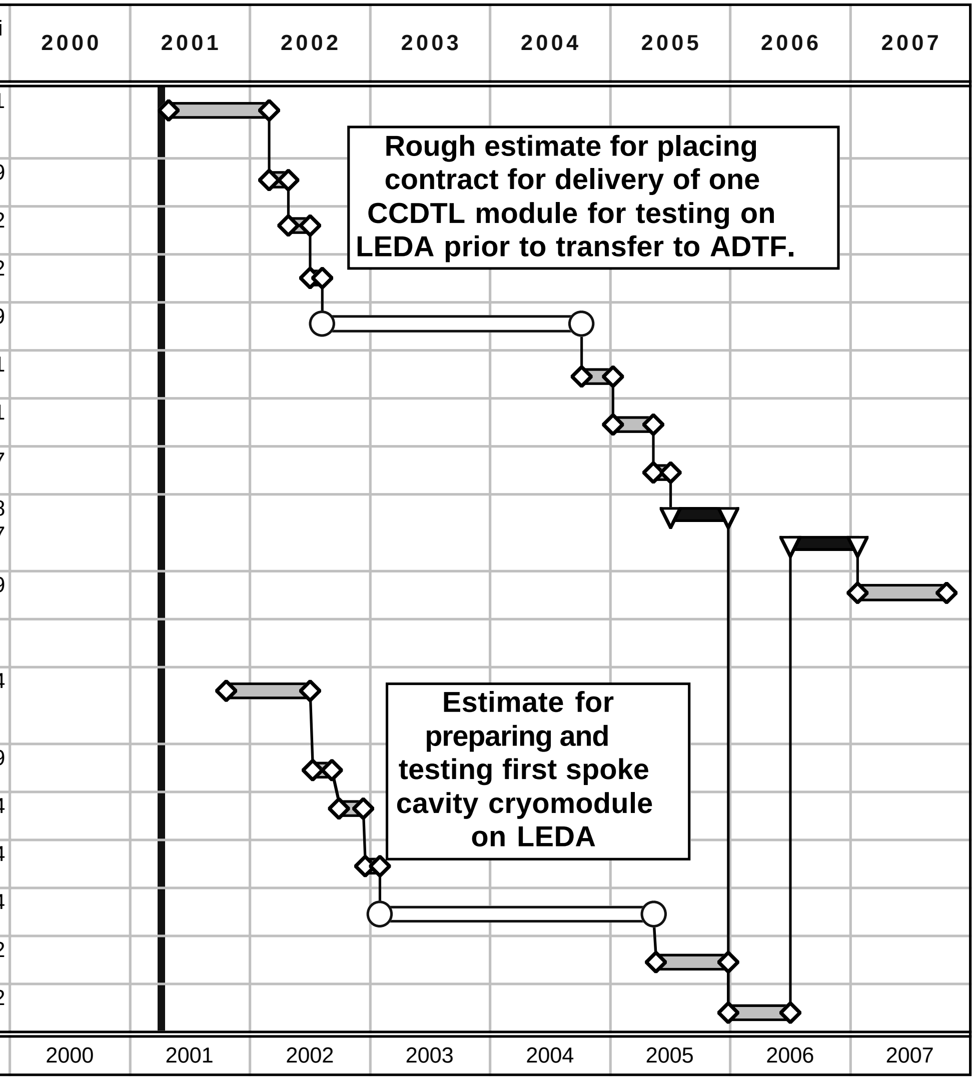
AAA

- Proposal (as depicted on following schedule) is to proceed immediately (as soon as funding is available) to procure one each low-beta module of CCDTL structure and one SCRF spoke cryomodule.
- LANL s role is to write the specs and requirements; and to develop special hardware such as tuners and power couplers.
- Industry will do the detailed design, fabrication and delivery.
- Each accelerator module can be tested with beam on LEDA.
- This approach gives the earliest possible tech transfer, hardware delivery, and beam test.
- It allows making the final ADTF technology decision based on industry capabilities and/or beam performance.

AAA

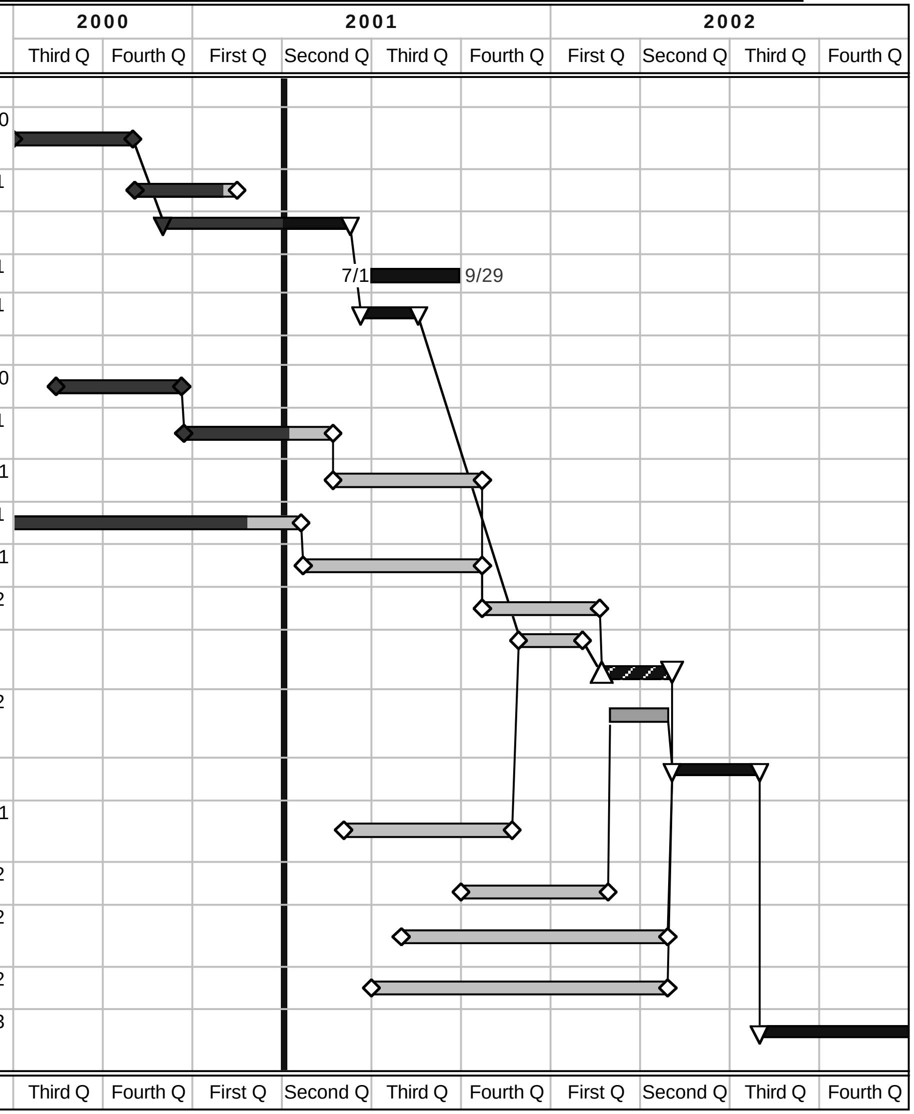
An Aggressive Schedule Approach for ADTF Accelerator

Activity Name	Start Date	Finish Date	Duration
Complete CCDTL design for bid package	4/27/01	2/28/02	10.1
Place ad	2/28/02	4/27/02	1.9
Evaluate responses	4/27/02	7/2/02	2.2
Place contract	7/2/02	8/7/02	1.2
Construction and delivery	8/8/02	10/5/04	25.9
Acceptance, checkout	10/5/04	1/8/05	3.1
Installation	1/8/05	5/12/05	4.1
Prepare for beam	5/12/05	7/2/05	1.7
Beam tests	7/2/05 7/2/06	12/24/05 1/22/07	5.8 6.7
Move hardware to ADTF	1/22/07	10/19/07	8.9
SCRF Spoke Structures			
Prepare bid package for spoke cryomodule	10/20/01	7/2/02	8.4
Place ad	7/9/02	9/6/02	1.9
Evaluate responses	9/28/02	12/10/02	2.4
Place contract	12/17/02	1/30/03	1.4
Construction and delivery	1/30/03	5/12/05	27.4
Acceptance and checkout	5/19/05	12/24/05	7.2
Installation	12/24/05	7/2/06	6.2



Major LEDA Activities for FY 2001

Activity Name	Start Date	Finish Date
Halo Measurement		
Complete Hardware Installation	7/1/00	10/31/00
Diagnostics Commissioning	11/2/00	2/15/01
Beam Measurements	12/1/00	6/9/01
Summarize Performance	7/1/01	9/29/01
Reliability checks	6/20/01	8/18/01
CCDTL		
Replace Defective Endwall	8/14/00	12/22/00
Braze, tune, assm Sect 2	12/23/00	5/22/01
Hot-model test of Sect 2	5/23/01	10/22/01
Machining of Sect 1	6/22/00	4/21/01
Tune, Braze, assm Sect 1	4/22/01	10/22/01
Integrated Assm & Tuning	10/23/01	2/20/02
Install on beamline	2/21/02 11/29/01	5/2/02 2/2/02
Perform checks & readiness assessment	3/1/02	4/30/02
Beam Testing	5/2/02	8/1/02
Build RCCS, vacuum systems	6/2/01	11/21/01
Prepare CCDTL diagnostics	10/1/01	2/28/02
Integrate 350 & 700-MHz LLRF	8/1/01	4/30/02
Add, Integrate Controls	7/1/01	4/30/02
Extended beam testing & addl halo measurements	8/1/02	1/30/03

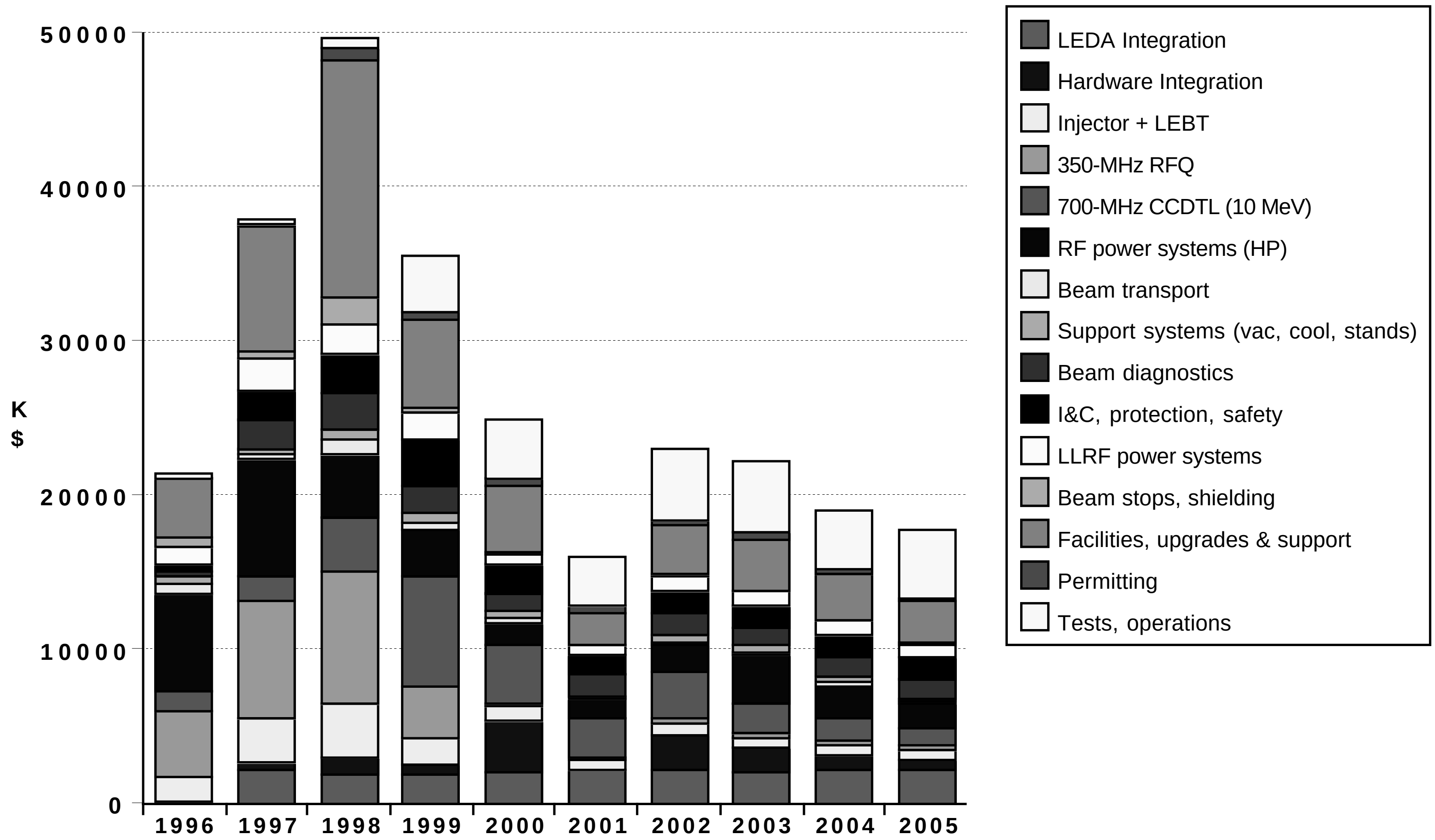


Dave Schneider, AAA-TPO

March 30, 2001, Rev 5

AAA

LEDA Annual Funding Needs by WBS level 2



The ADTF accelerator R&D program will help ensure much-improved linac operation on the ADTF facility.

¥ Much of the accelerator benefits from extensive development and detailed designs from APT.

¥ Proven operation on LEDA verifies the excellent integrated operation of the injector, RFQ, RF equipment, controls, and diagnostics.

¥ Additional development and testing on LEDA will demonstrate improved reliability and measure beam properties. This work will include addressing specific T/M needs.

¥ Both off-line and LEDA beam operations can better qualify ADTF linac hardware.

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

High Energy Linac RF Configurations for the APT-based ADTF Linac

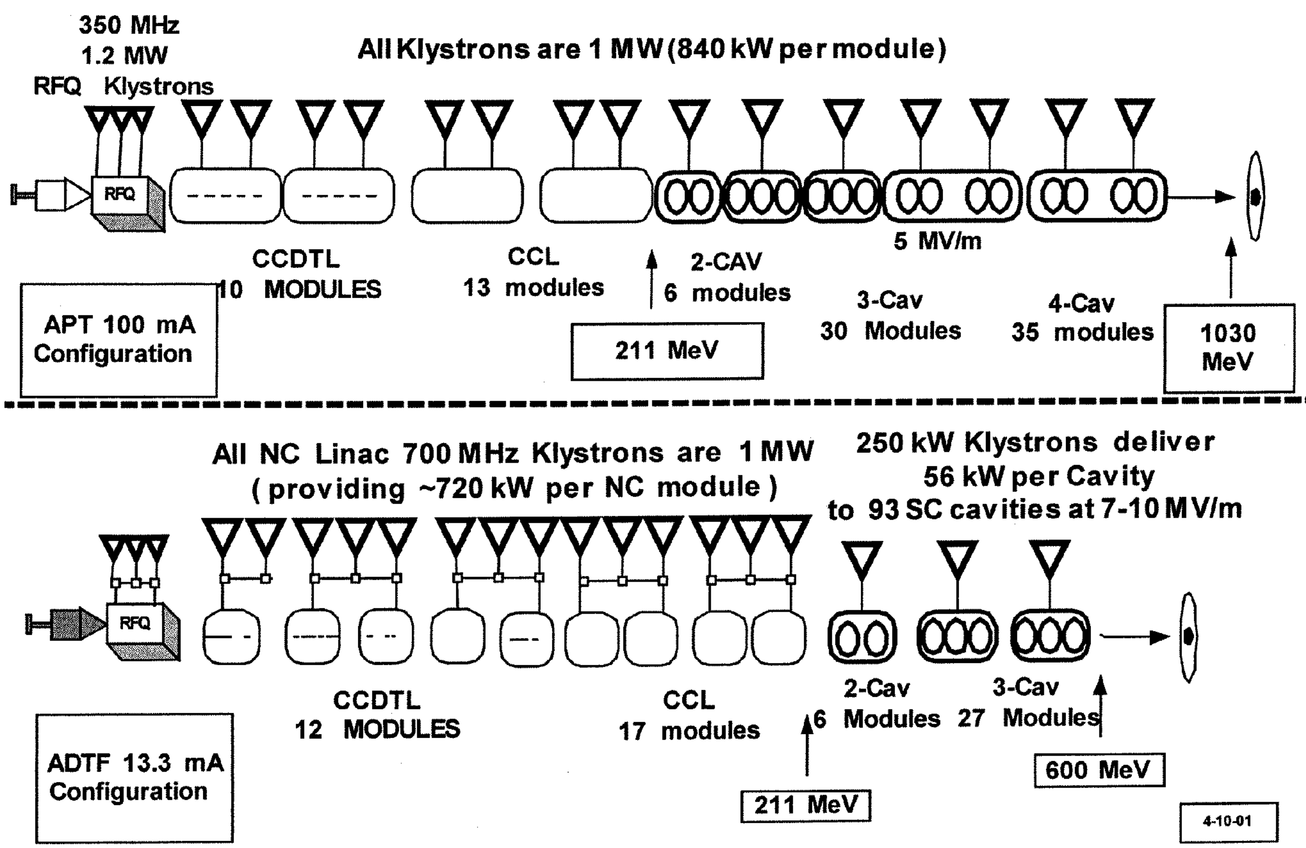
M. McCarthy PPO

Design Considerations

* Utility power grid impact of beam faults.
* Maintenance access and interchangeability by design.
* Increased reliability and control margin by derating klystrons.
* Minimize rf transport loss: waveguide vs coax.
* Minimize component count to increase MTBF.
* Minimize waveguide penetrations to reduce neutron streaming.
* Manufacturing schedules for major rf components.

* **Groundbreaking: 2004**

100 mA APT & 13 mA ADTF Reference Configurations



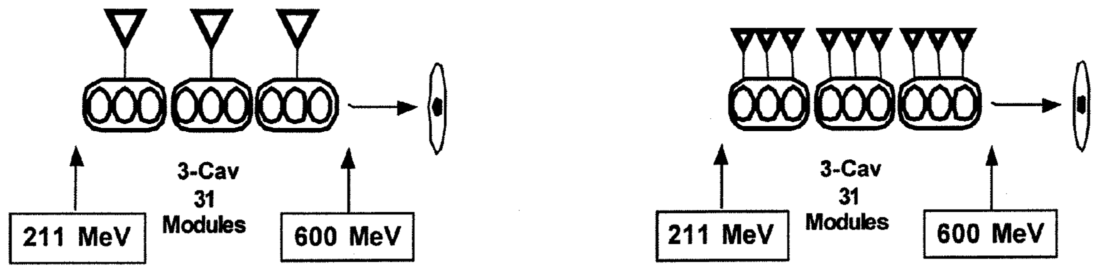
Basis for RF Power Options on High Beta SC Linac

Table 1-ADTF Strawman S2 Design Parameter Summary

	ADTF 13.3 mA	APT
	Section 5	0.64 Beta
Structure type	5-cell elliptical	5-cell elliptical
Win,section (MeV)	211	211
Wout,section (MeV)	600	471
Frequency (MHz)	700	700
Betag	0.64	0.64
E0T(MV/m)	7.0489	5
DW/cav (MeV)	3.288 to 4.219	~ 2.55
DW/section (MeV)	389	260
Cavities/cryomodule	3	2(first six), 3
Cavities/section	93	102
Cryomodules/section	31	6 2-Cav, 30 3-Cav
Section length (m)	191.596	211.5
Cav Pwr 13.3mA(kW)	56.1	37.24
Cav Pwr 100mA (kW)	422	280
Cavities per generator	3 or 1	3
Number rf generators	31 or 93	36

13.3 mA ADTF Configuration

Klystrons or IOTs deliver
56 kW per Cavity
to 3-Cav SC module at 7-10 MV/m



* 700 MHz, 56.1 kW delivered per cavity @ 7-10 MV/m

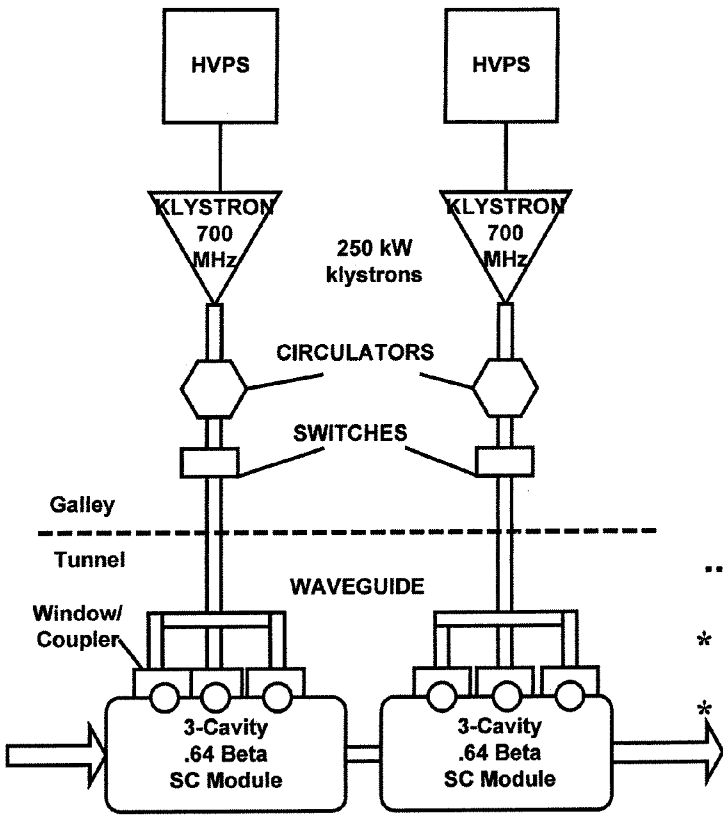
*168 kW per module, plus 12% control margin and 6% loss margin

* Add 25% reliability margin: 168kW*1.12*1.06*1.25 = 250 kW

* 250 kW per module rf source or 83 k/w rf source per individual cavity

4-10-01

One 250 kW 700 MHz Klystron per SC Module

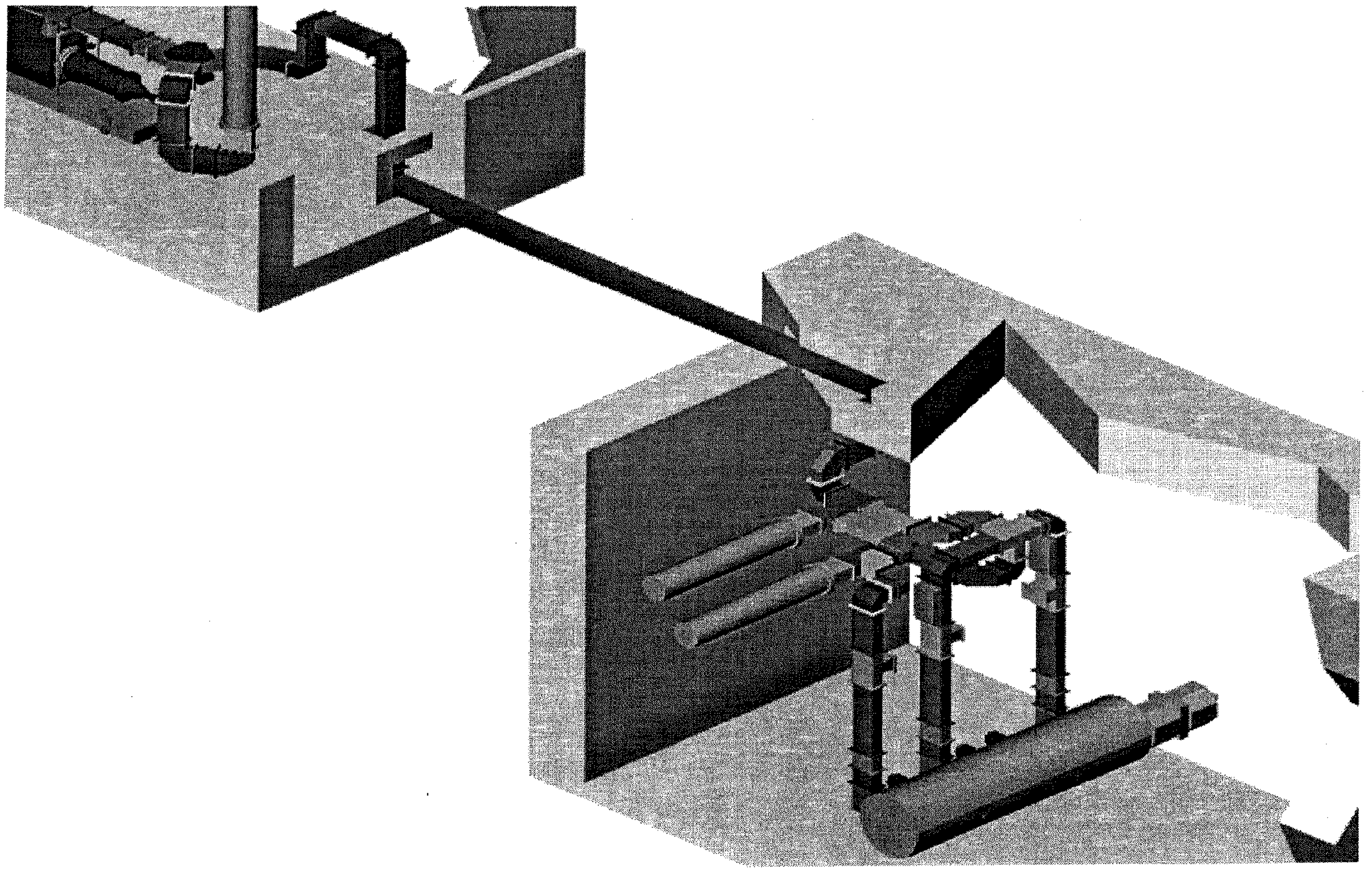


* Reduced parts count wrt individual IOT per cavity.
* Sharing HVPS by non-adjacent klystrons is feasible.
* One Conduit per module using full height waveguide in conduit.
* Excellent fault recovery time.
* Low technical risk.
* WG splitters and loads may be moved to the gallery to eliminate need of tunnel access.

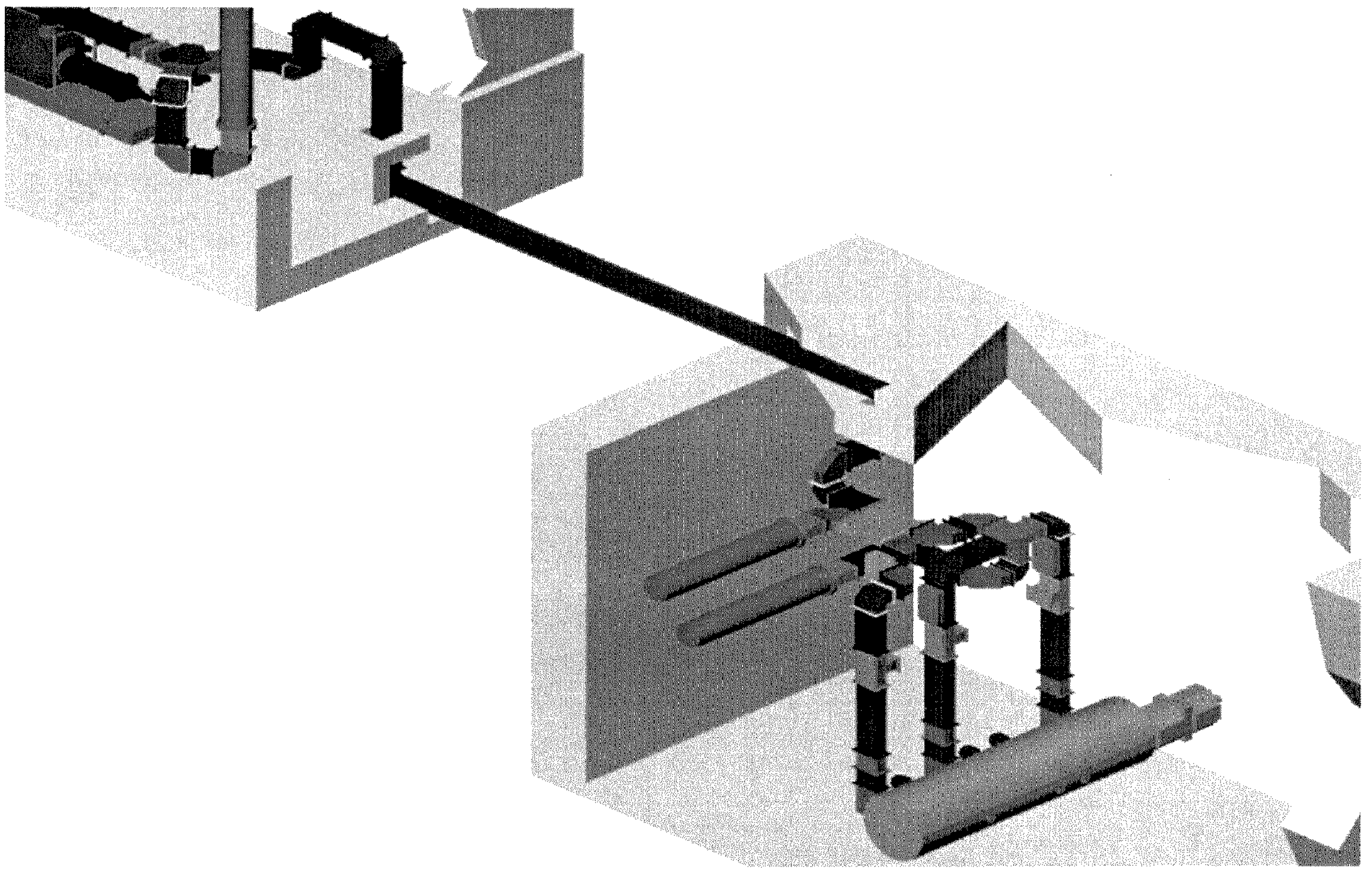
....

* Averaged cavity phase and amplitude control.
* Waveguide splitter components in tunnel.

One klystron per 3-Cavity SC Module Configuration

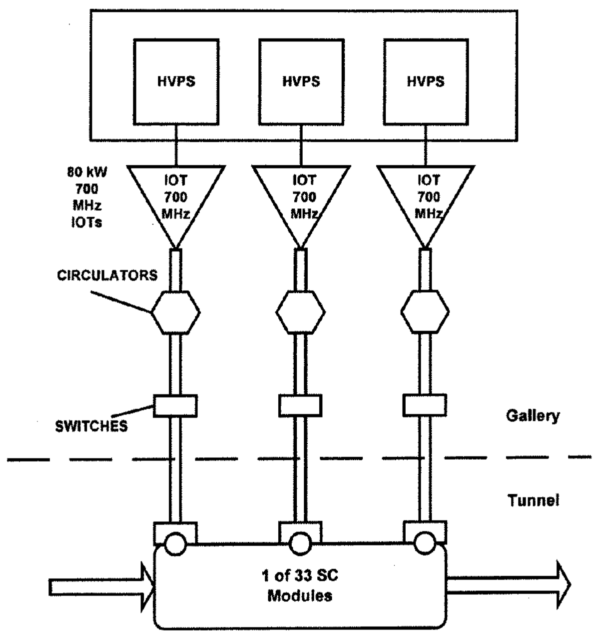


One klystron per 3-Cavity SC Module Configuration



Three 83 kW 700 MHz IOTs per SC Module

One IOT per Cavity Configuration

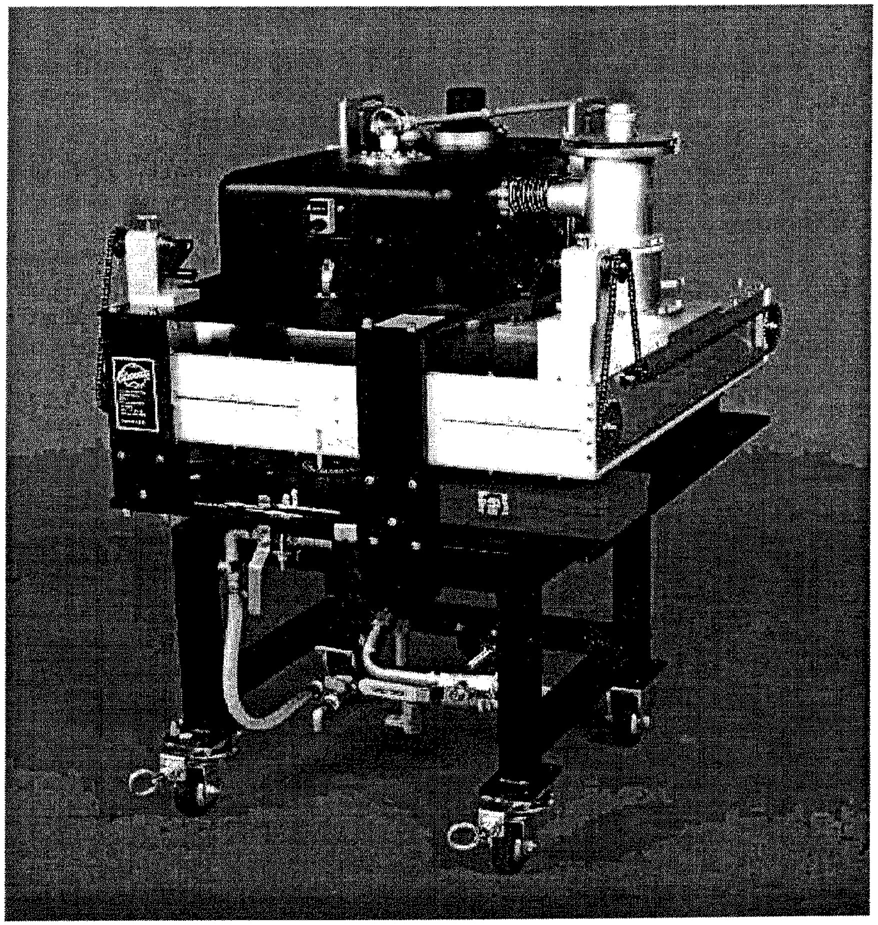


- * Individual Cavity Phase and Amplitude Control.
- * Reliable and efficient IOT power.
- * One HVPS per three IOTs is feasible.
- * One Conduit per SC module by using 1/4 Height waveguide in conduit or 6" coax.
- * Excellent fault recovery time and impact.
- * Reduced X-ray shielding required around IOTs.
- * 100 mA operation achieved by replacing each IOT with a 500kW klystron (@ 7 MV/m, no additional SC modules are required).

....

- * Nearly three times the amount of RF components per superconducting module resulting in higher cost and complexity per module.
- * Some IOT development required.

EIMAC Inductive Output Tube



* 35 kW average output power used for commercial TV.

* Vendor says 150 kW is not a serious technical risk ($800-1200 k development cost).

* Efficiency ~ 70% at all power levels.

* Relatively inexpensive HVPS required. May share one HVPS for multiple IOTs.

*Tube replacement takes less than 10 minutes.

* X-ray shielding requirement is minimal.

RF System Availabiltiy Spreadsheet

One 250 kW RF Source per Cryomodule		13.3 mA capability		
HE Linac RF only	31 Modules			
ADTF Estimate	MTBF	#	MTTR	MEAN TIME
	(HOURS)	RF System	(HOURS)	BETWEEN
No Spares		Component	Beam-Off	FAILURES
Low Energy Only		with spares	time	(HOURS)
Solenoid PS	100000	62	8.00E-04	1613
Solid State Amp Circuit	100000	31	8.00E-04	3226
Klystron Water System	100000	31	8.00E-04	3226
Filament Power Supply	100000	31	8.00E-04	3226
VAC-ION HVPS	100000	31	8.00E-04	3226
IOC & HPP Interface	40000	31	8.00E-04	1290
PLC Controller&Connections	24000	31	8.00E-04	774
HVPS	30000	31	8.00E-04	968
KLYSTRON (250 kW)	50000	31	8.00E-04	1613
CIRCULATOR	60000	31	8.00E-04	1935
Circulator Load	60000	31	8.00E-04	1935
Waveguide/ Water Sys	100000	31	8.00E-04	3226
LLRF	50000	31	8.00E-04	1613
Tunnel Componets				
Magic-Tee Loads	50000	62	4	806
Auto phase shifter	50000	62	4	806
Waveguide/Water System	100000	29	4	3448
RF WINDOW	400000	93	24	4301
Downtime per Runtime Year				
Runtime Year Availability				
Note: MTTR is beam-off time. This is the time it takes to isolate an rf station and bring the bea				
Cost at $3 per Watt installed.		$23,250,000		

RF System Availabiltiy Spreadsheet

One 250 kW RF Source per Cryomodule					
HE Linac RF only	31 Modules	# Spares =	0		
ADTF Estimate	MTBF	#	#	#	DOWN
	(HOURS)	FAILURES	FAILURES	FAILURES	TIME
No Spares		PER	< 100 Sec	> 100 Sec	(HOURS)
Low Energy Only		Runtime Year			
Solenoid PS	100000	4.8	0.0	0.0	0.0
Solid State Amp Circuit	100000	2.4	0.0	0.0	0.0
Klystron Water System	100000	2.4	0.0	0.0	0.0
Filament Power Supply	100000	2.4	0.0	0.0	0.0
VAC-ION HVPS	100000	2.4	0.0	0.0	0.0
IOC & HPP Interface	40000	6.0	0.0	0.0	0.0
PLC Controller&Connections	24000	10.0	0.0	0.0	0.0
HVPS	30000	8.0	0.0	0.0	0.0
KLYSTRON (250 kW)	50000	4.8	0.0	0.0	0.0
CIRCULATOR	60000	4.0	0.0	0.0	0.0
Circulator Load	60000	4.0	0.0	0.0	0.0
Waveguide/ Water Sys	100000	2.4	0.0	0.0	0.0
LLRF	50000	4.8	0.0	0.0	0.0
Tunnel Componets					
Magic-Tee Loads	50000	9.6	0.0	9.6	38.2
Auto phase shifter	50000	9.6	0.0	9.6	38.2
Waveguide/Water System	100000	2.2	0.0	2.2	8.9
RF WINDOW	400000	1.8	0.0	1.8	43.0
Downtime per Runtime Year		81.3	0.0	23.1	128.5
Runtime Year Availability					0.9838
Note: MTTR is beam-off time. This is the time		m back to full operation.			
Cost at $3 per Watt installed.					

ADTF HE RF Option Summary

AAA

SC Linac Configuration	Beam trips>300 ms, (No. Faults > 300 ms< 100 Sec)	# Faults over 100 sec.	Relative Percent Availability	Relative RF System Cost @ $3.00/Watt (Installed).	Normalized Cost	Notes:
13.3 mA One 250 kW klystron per module	0, (58.2)	23.15	0.984	$23,250,000	1.00	Least expensive.
13.3 mA One 83kW IOT per Cavity	0, (142.2)	2.99	0.994	$25,574,898	1.10	Least faults under 100 sec. Control of individual cavity phase and amplitude.
100 mA One 500 kW klystron per cavity	0, (142.2)	4.18	0.993	$153,450,000	6.60	Path to 100 mA beam. Individual cavity phase & amplitude cntl.
100 mA One 1 MW klystron per cavity	0, (73.5)	24.69	0.983	$144,000,000	5.63	Path to 100 mA beam. 5 MV/m, 448 MeV at cavity 93.

AAA

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

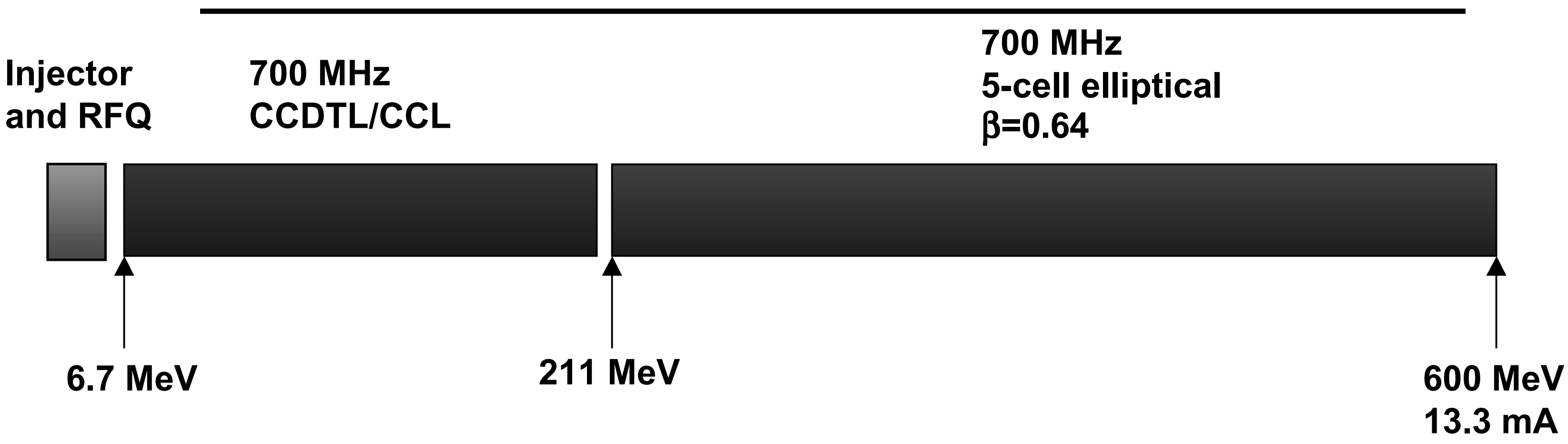
ADTF Reference Low-Energy Linac Beam Dynamics

Robert Garnett

Outline

- **Description of ADTF Reference Design Parameters**
  - ***Proposed Changes from APT Baseline***
  - ***Impact on Beam Dynamics / Physics***
- **Preliminary Beam Dynamics Results**
- **Summary**

ADTF Reference Design - Proposed Changes from APT



¥ Eliminate β = 0.82 5-cell SC elliptical cavities - Simpler design.

¥ Eliminate 1 x 3 CCDTL cavities   Engineering considerations.

• Modify Synchronous Phase and Accelerating Gradient Ramps:

1) More aggressive acceleration reduces overall linac length— Saves 28 m.

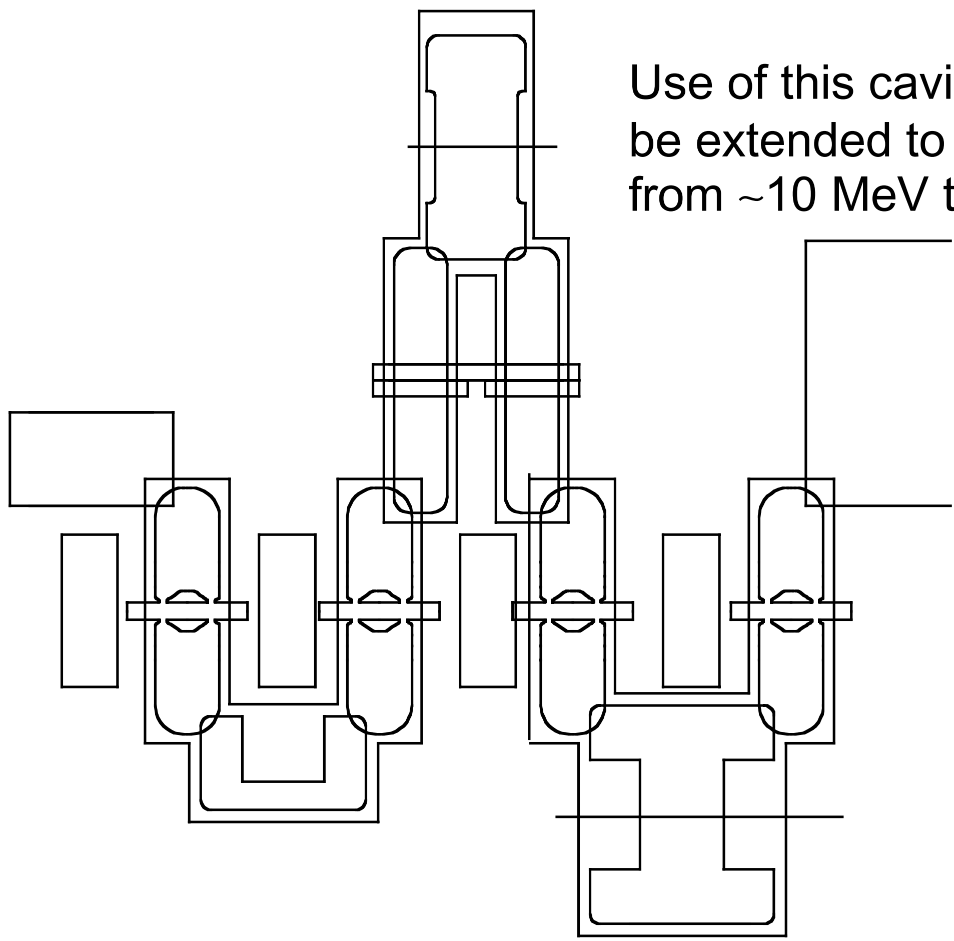
2) CCDTL heat transfer experiments show structure cooling is better than expected ⇒ Can tolerate higher structure power densities.

• Focusing period changed to 8-βλ throughout— increases transverse focusing.

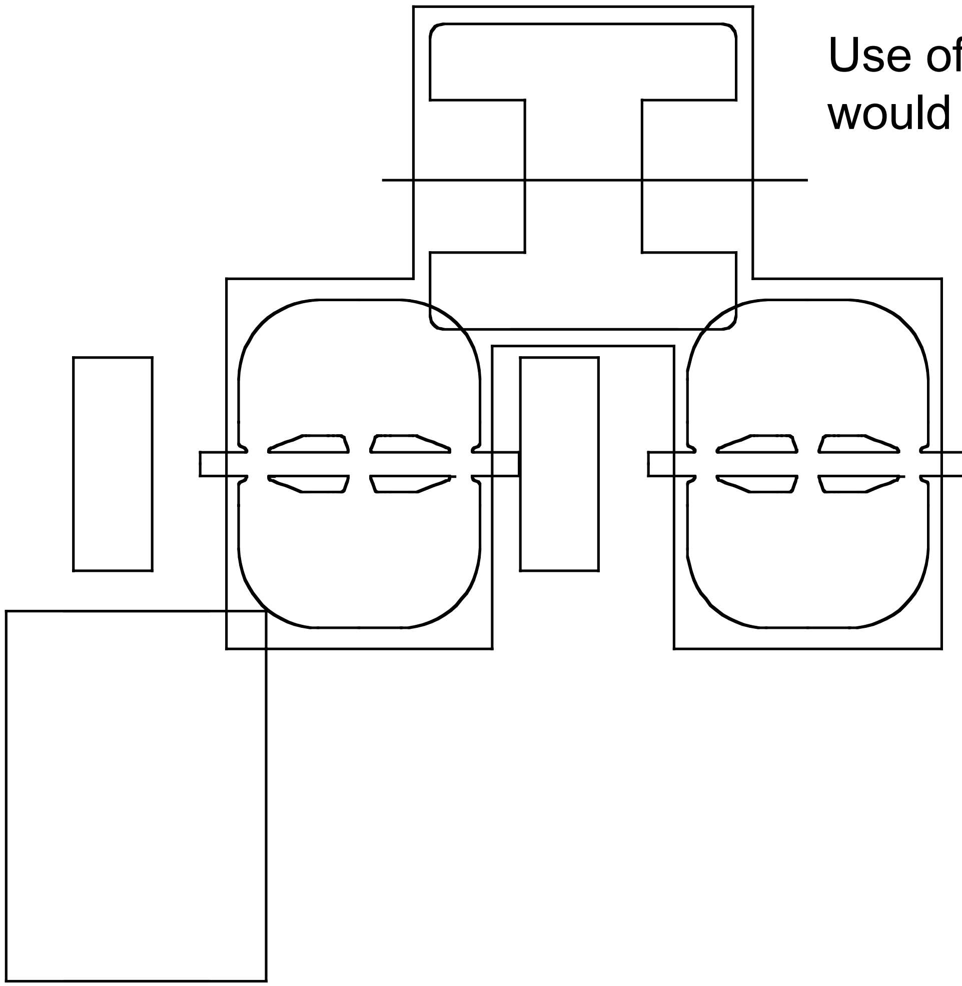
• RF partitioning optimized for 13.3 mA changes RF module energy transitions.

9MeV CCDTL (1 x 2-gap)

Use of this cavity type would be extended to higher energy from ~10 MeV to ~30 MeV.

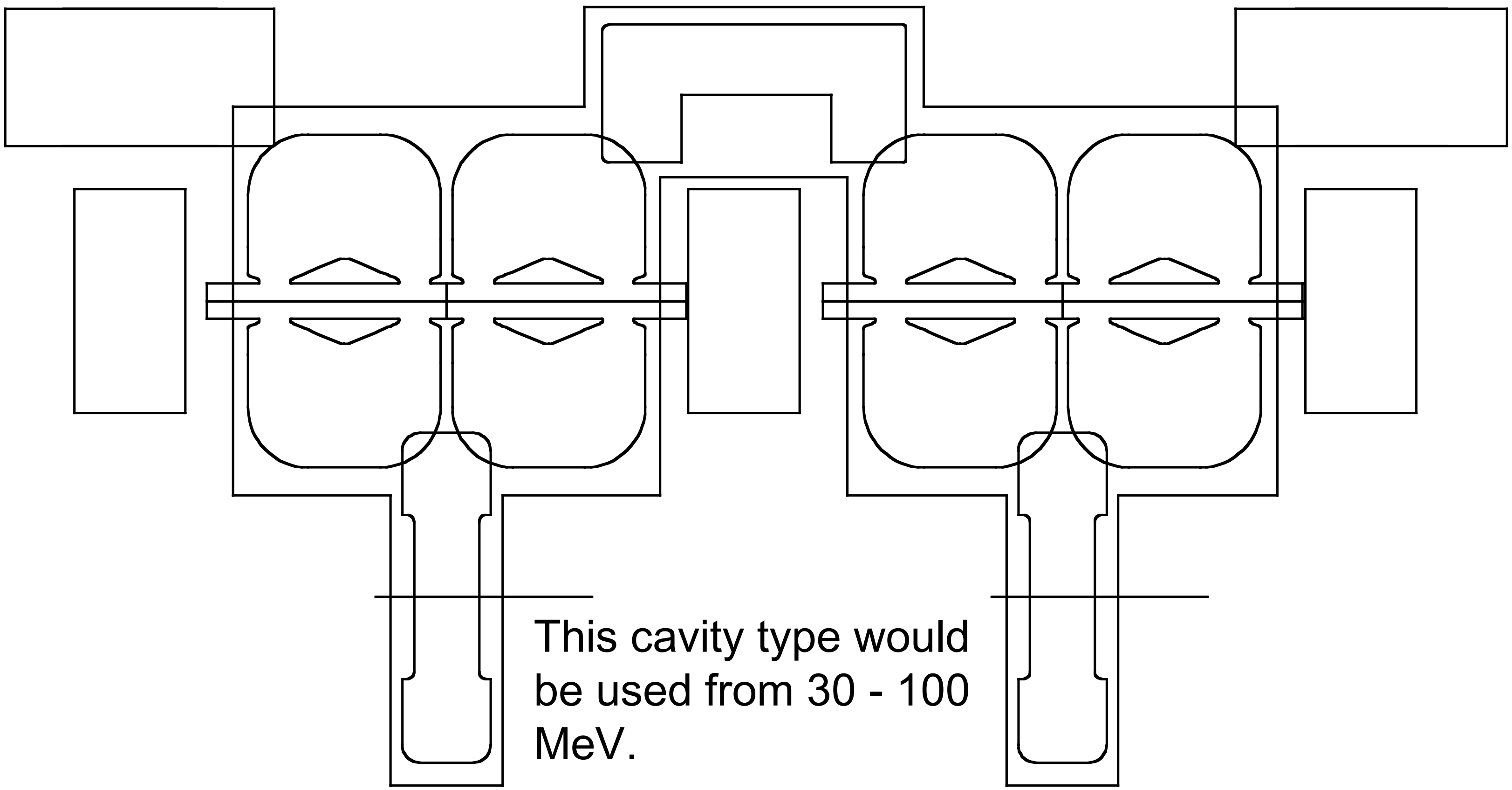


23MeV CCDTL (1 x 3-gap)



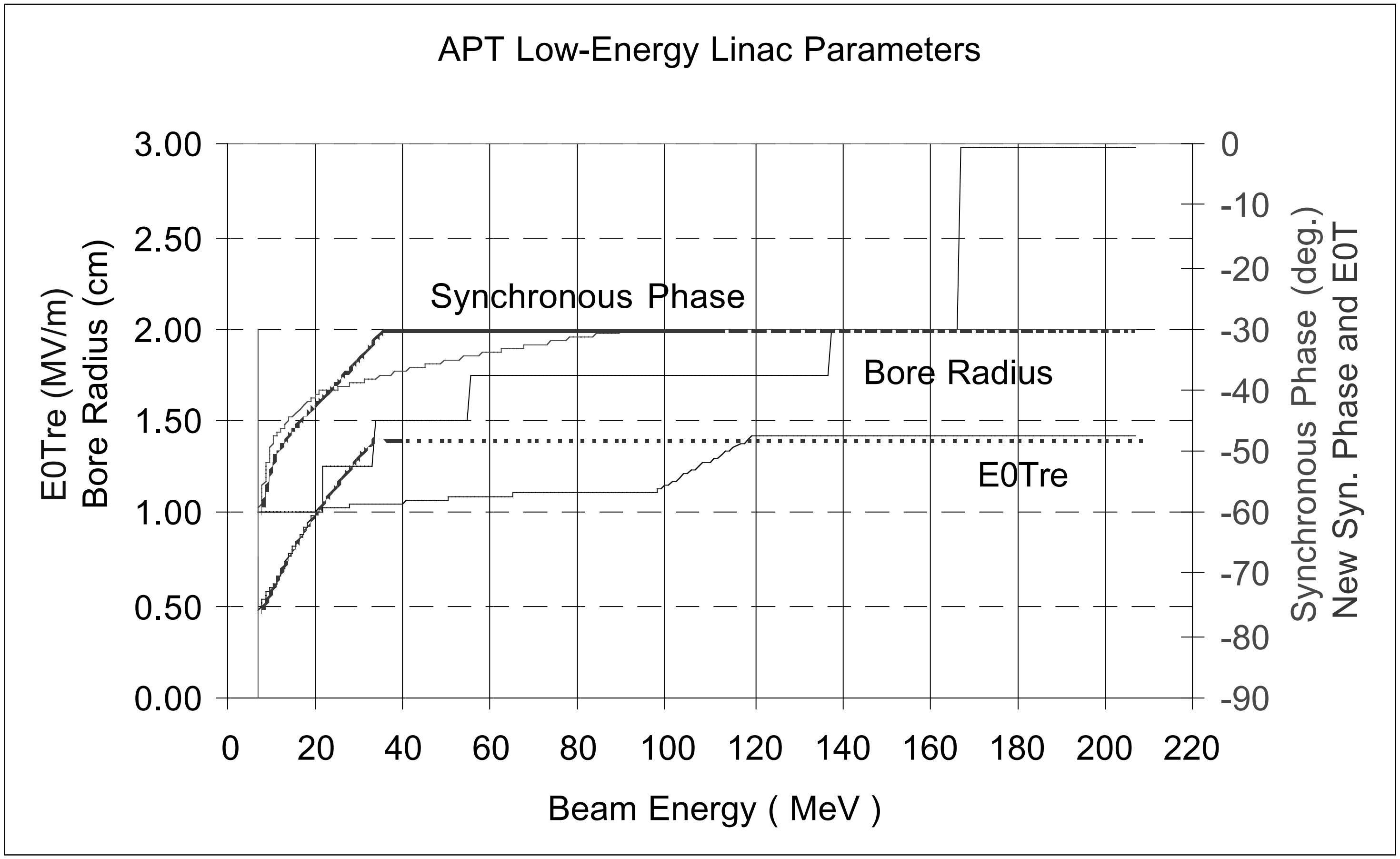
Use of this cavity type would be eliminated.

36MeV CCDTL (2 x 2-gap)



This cavity type would be used from 30 - 100 MeV.

Synchronous Phase and Accelerating Gradient



ADTF Reference LE Linac Beam Simulations

AAA

- 10,000 macroparticle distributions from LEDA RFQ simulations used as input to the PARMILA code:

  Beam currents 13.3 mA, 100 mA

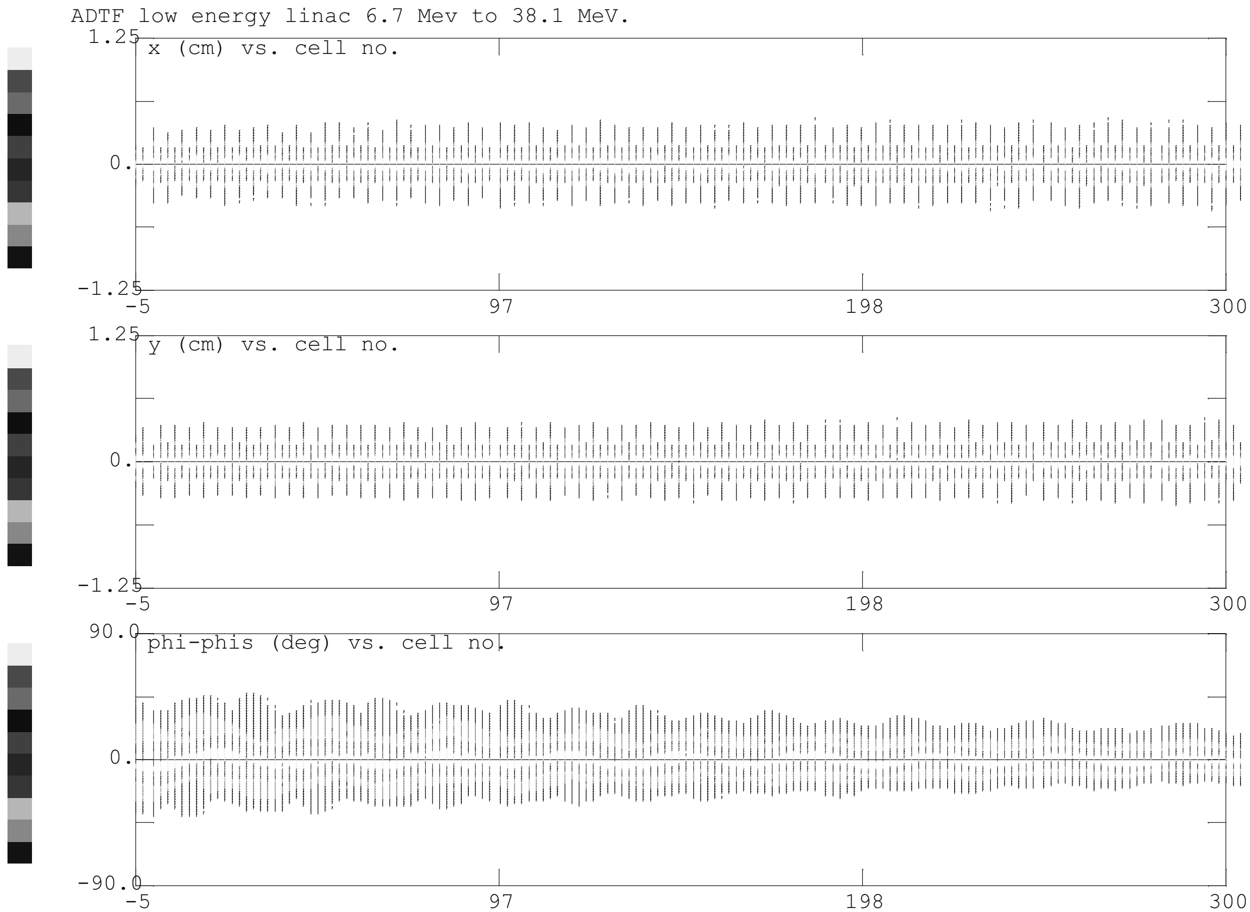
- Preliminary simulations from 6.7 to 40 MeV only

  Additional cavity modeling required for 2 x 2-gap cavities in progress.

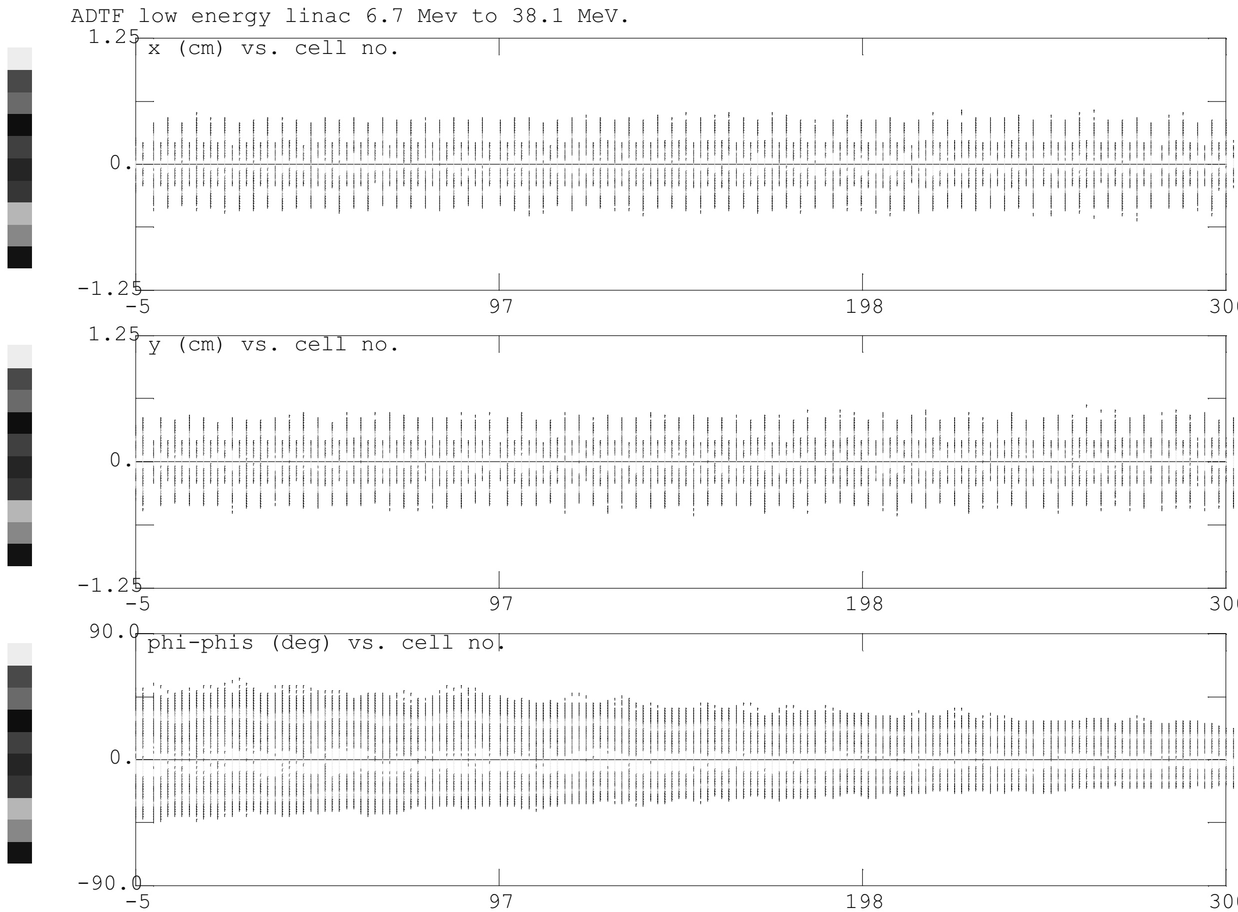
- Ideal linac simulated no alignment or operational errors included.
- Preliminary results look excellent!

Beam Simulation Results - 13.3 mA

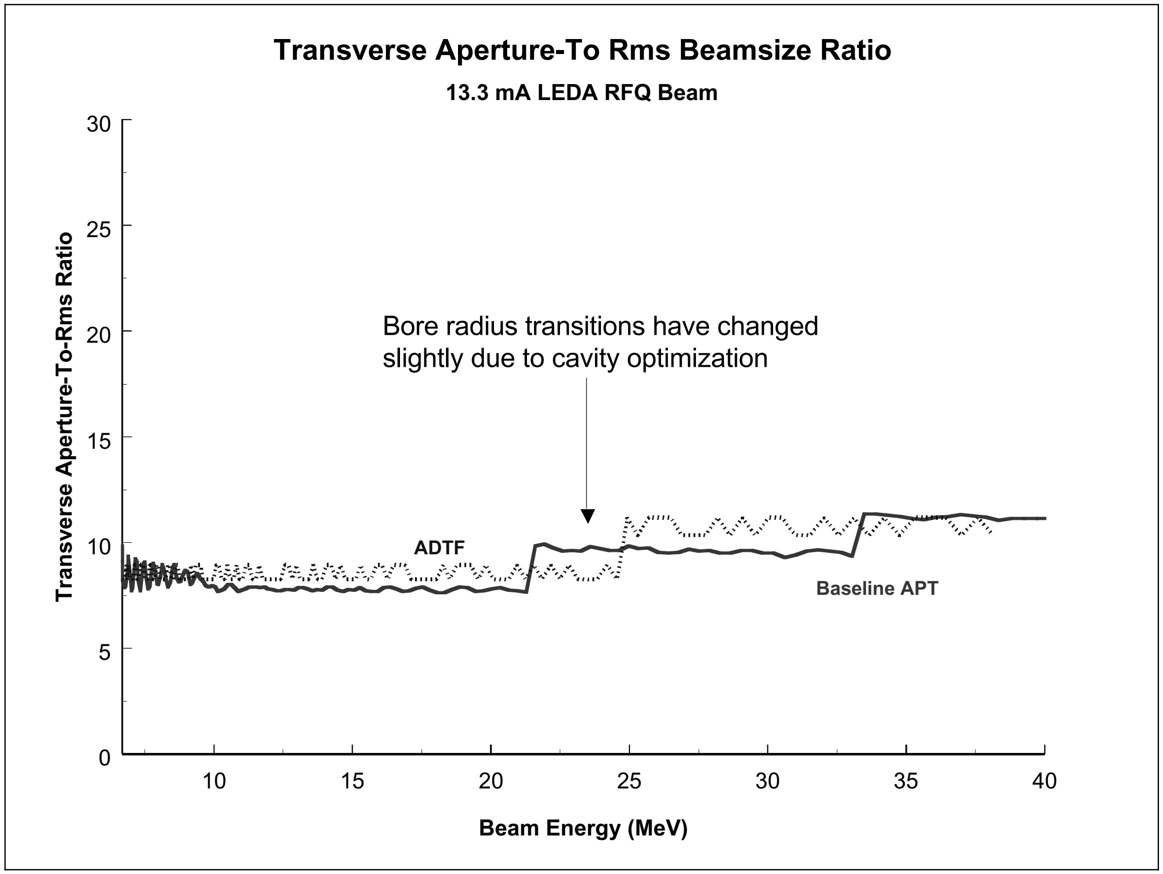
10,000 Macroparticle LEDA RFQ Distribution, 6.7 - 40 MeV



Beam Simulation Results - 100 mA
10,000 Macroparticle LEDA RFQ Distribution, 6.7 - 40 MeV



Comparison to Baseline APT
13.3 mA LEDA RFQ Distribution, 6.7 - 40 MeV



Summary

- ADTF low-energy reference linac is based on APT.

  Only minor changes are made to the design.

- We expect no impact on the beam physics as a result of the proposed modifications for ADTF:

  Current-Independent matching is unaffected.

  Equipartitioning maintained and/or required?

  Are the alignment and operational error budgets changed? Error studies

- Preliminary simulation results show excellent performance for the ADTF low-energy reference design.

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10, 2001

ADTF Reference LE Linac Design Description

Richard Wood

NC Low-Energy Linac Topics

¥ Brief historical look at design issues and assumptions.

¥ Description of current favored design for ADTF.

¥ Some beam dynamics results for new design. (Garnett)

¥ Update on recent ED&D efforts, results, conclusions.

¥ Remaining ED&D needs, costs, possible schedule.

TPO-RGN-1003

AAA

LEL History, Options, & Status

	OLD APT	Costed ADTF	New APT	ADTF Proposal	Tolerant ADTF Option
Focus Lattice	$8/9^{\beta\lambda}$	$8^{\beta\lambda}$	$8^{\beta\lambda}$	$8^{\beta\lambda}$	$8^{\beta\lambda}$
1X2-gap CCDTL					
Final Energy	10.16 MeV	28.7 MeV	38.0 MeV	36.8 MeV	37.1 MeV
Length	11.2 m	39.3 m	45.9 m	44.9 m	47.8 m
1X3-gap CCDTL					
Final Energy	21.6 MeV	- N. A. -	- N. A. -	- N. A. -	- N. A. -
Length	19.21 m				
2X2-gap CCDTL					
Final Energy	96.7 MeV	97.6 MeV	97.5 MeV	99.3 MeV	99.7 MeV
Length	83.0 m	54.7 m	45.8 m	48.2 m	48.3 m
CCL	7-cell	6-cell	6-cell	6-cell	6-cell
Final Energy	211 MeV	211 MeV	212.0 MeV	210.7 MeV	211.2 MeV
Length	95.7 m	86.2 m	88.2 m	85.7 m	85.8 m
Overall Length	209.1 m	180.3 m	179.9 m	178.9 m	182.0 m
# 1-MW klystrons					
@100mA	52	72	61	70	65
@13.3mA		44	45	41	55
recovery time		1-5 sec ?	1-5 sec ?	1-5 sec ?	<<0.3 sec

Shaded items are all very preliminary.

Simplified new design side-steps several unresolved ED&D issues.

¥ Reverts to original 8__ lattice:
- —Eliminates problematic oblong coupling cavities in 2X2-gap CCDTL
- —Eliminates equally complex bridge coupler in 1X3-gap CCDTL.
- —Increases net packing density for better efficiency.
- —Possibly eliminates 3-gap CCDTL all together.

¥ Takes advantage of improved cooling results in 2X2-gap CCDTL.
- —In conjunction with the higher packing factor, this allows higher E_0T, shortens linac, saves installed cost.

¥ Employ improved CCDTL cavity shapes that improve shunt impedance and gain needed magnet clearance.

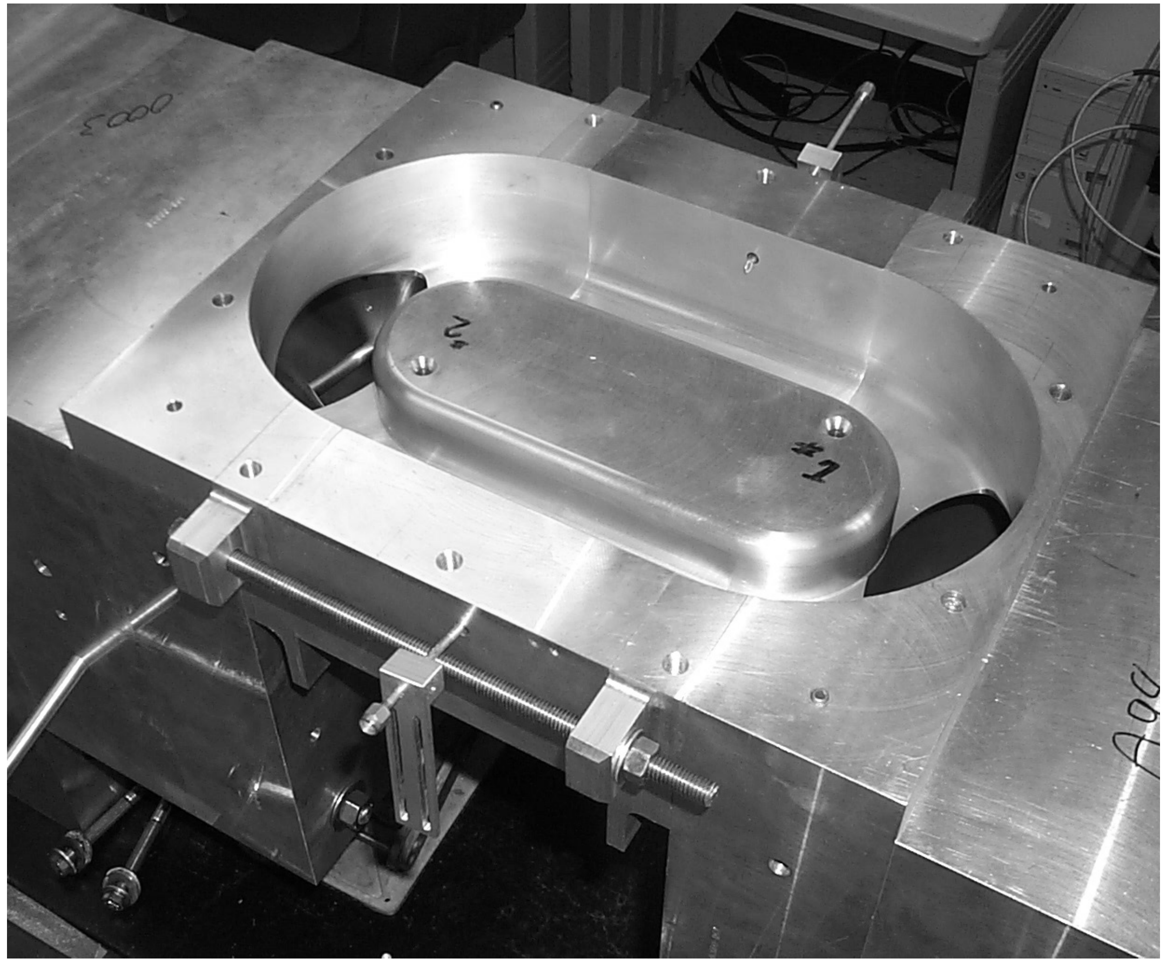
In old 9 __ lattice, latter 2X2-gap segments are too far apart for round coupling cavity

¥ Oblong coupling cavity was born. Cold model by AES is shown.

¥ Best coupling achieved was low, <3%. Too low for long Supermodule. Might be okay with shorter module.

¥ Longest oblong cavity could have competing resonant modes.

¥ Complicated fab, tuning, and cooling.



RF Modules were made shorter to address a number of concerns.

¥ Smaller # of cavities per module decreases the number of possible nearby structure modes.

—Removes overly tight cold   tuning tolerances.

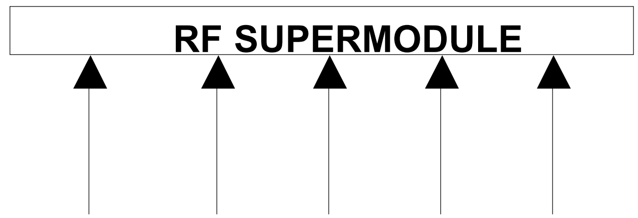
—Relaxes coupling cavity cooling tolerances.

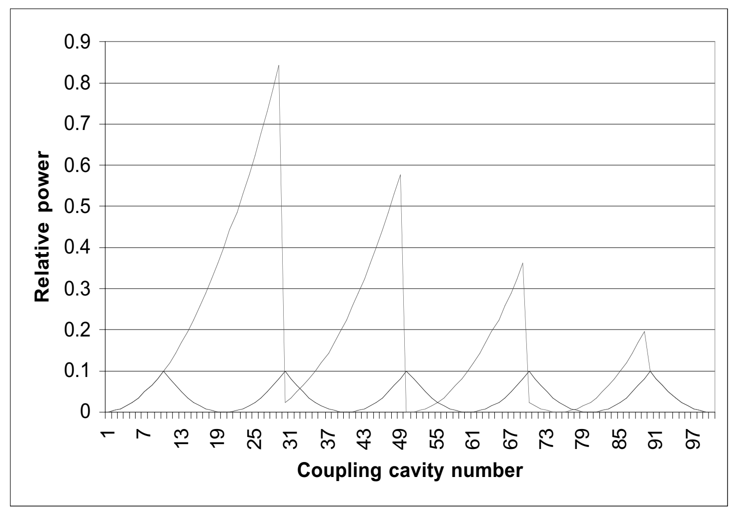
¥ Shorter modules avoid the significant thermal expansion and seismic restraint challenges posed by long Super-modules .

¥ Avoids complicated coupling cavity cooling system that may be required with multi-klystron   Super-modules.

Long Super-modules raise questions about variable coupling-cavity thermal loads which could result in run away stop-band problems.

- In original Super-module concept, each N-klystron module has N+1 klystrons installed.
- When one klystron is down, those remaining continue full beam operation.
- This produces at least N+2 power-flow distributions, with markedly different c-cavity thermal loads.
- Probably requires tailored coolant distribution for each klystron combination.





Reconfiguration philosophy

All of the issues listed above fall into one of three categories:

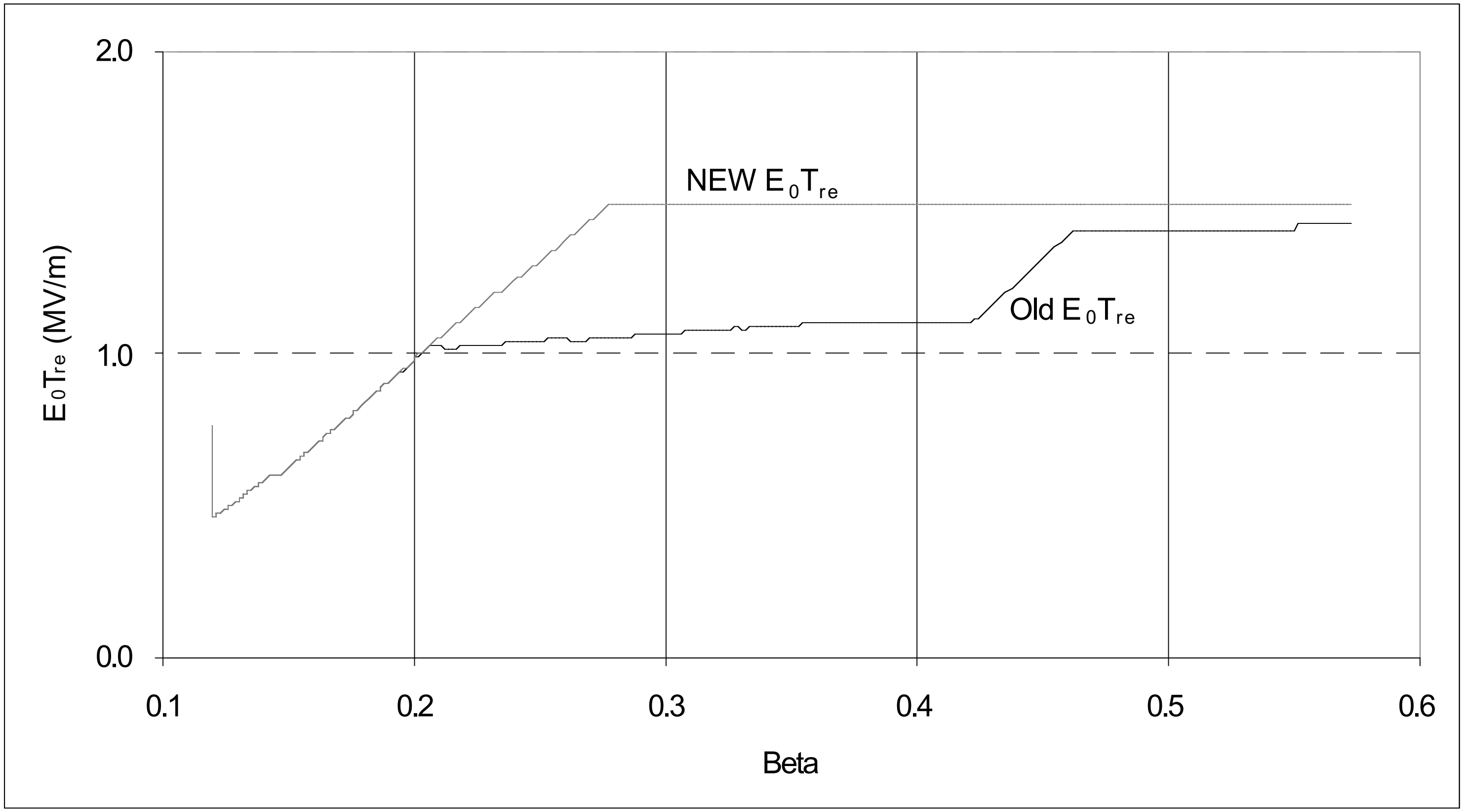
- Perceived problems (not necessarily real).
- Design, fabrication, or tuning inconveniences.
- Simple unknowns.

All are considered solvable, given time, people, money. But the cost/benefit is now considered marginal for most of them. The proposed simplifications seem at least prudent.

ADTF LE Linac
approx. 4/4/01
Mod 25
Mod 26
Mod 27
Mod 21
Mod 22
Mod 23
Mod 24
6-cell
CCL
Mod 17
Mod 18
Mod 19
Mod 20
Mod 13
Mod 14
Mod 15
Mod 16
Mod 9
Mod 10
Mod 11
Mod 12
2X2-gap
CCDTL
Mod 6
Mod 7
Mod 8
Mod 3
Mod 4
Mod 5
1X2-gap
CCDTL
Mod 1
Mod 2

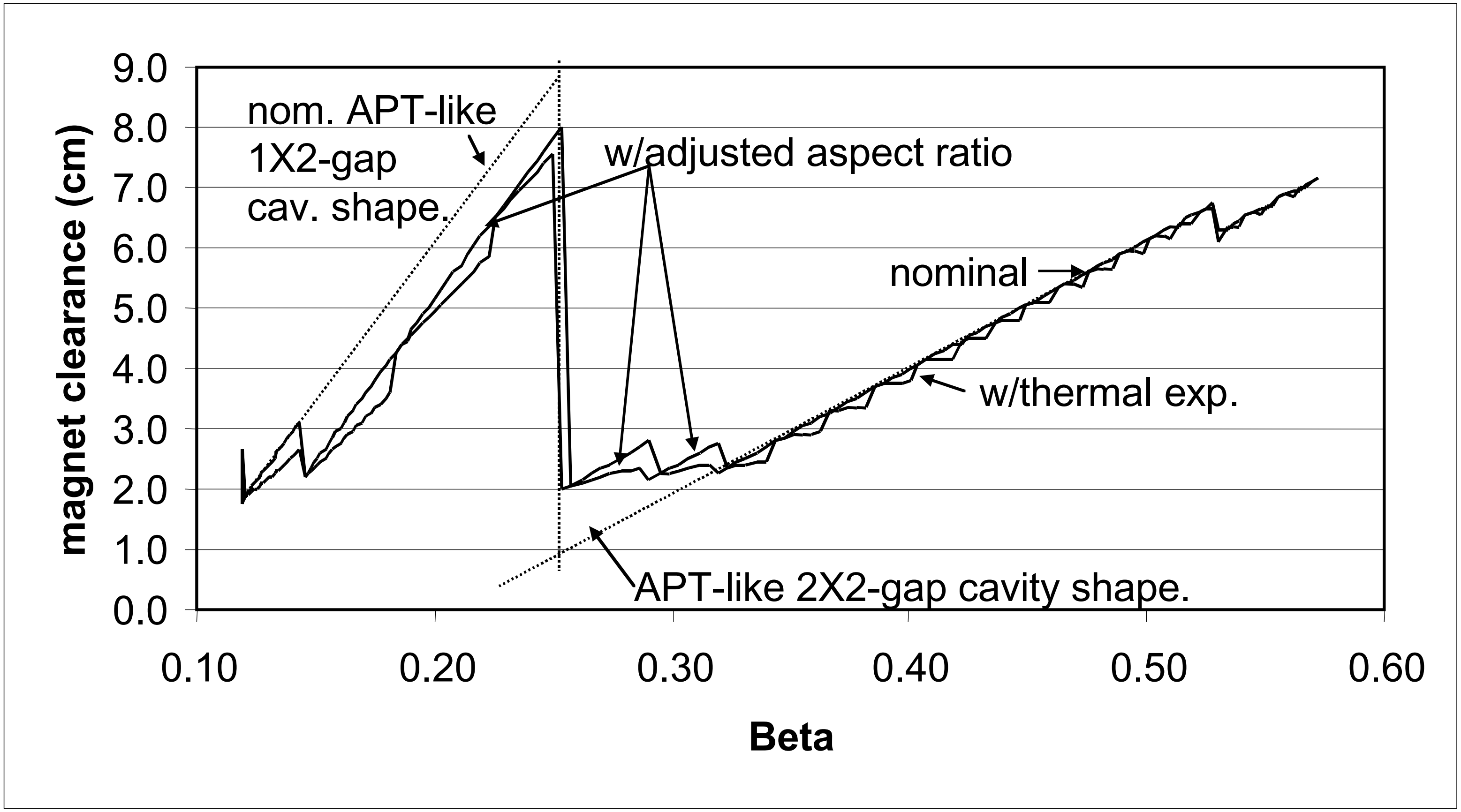
New normal-conducting LEL design uses higher accelerating gradient.

AAA

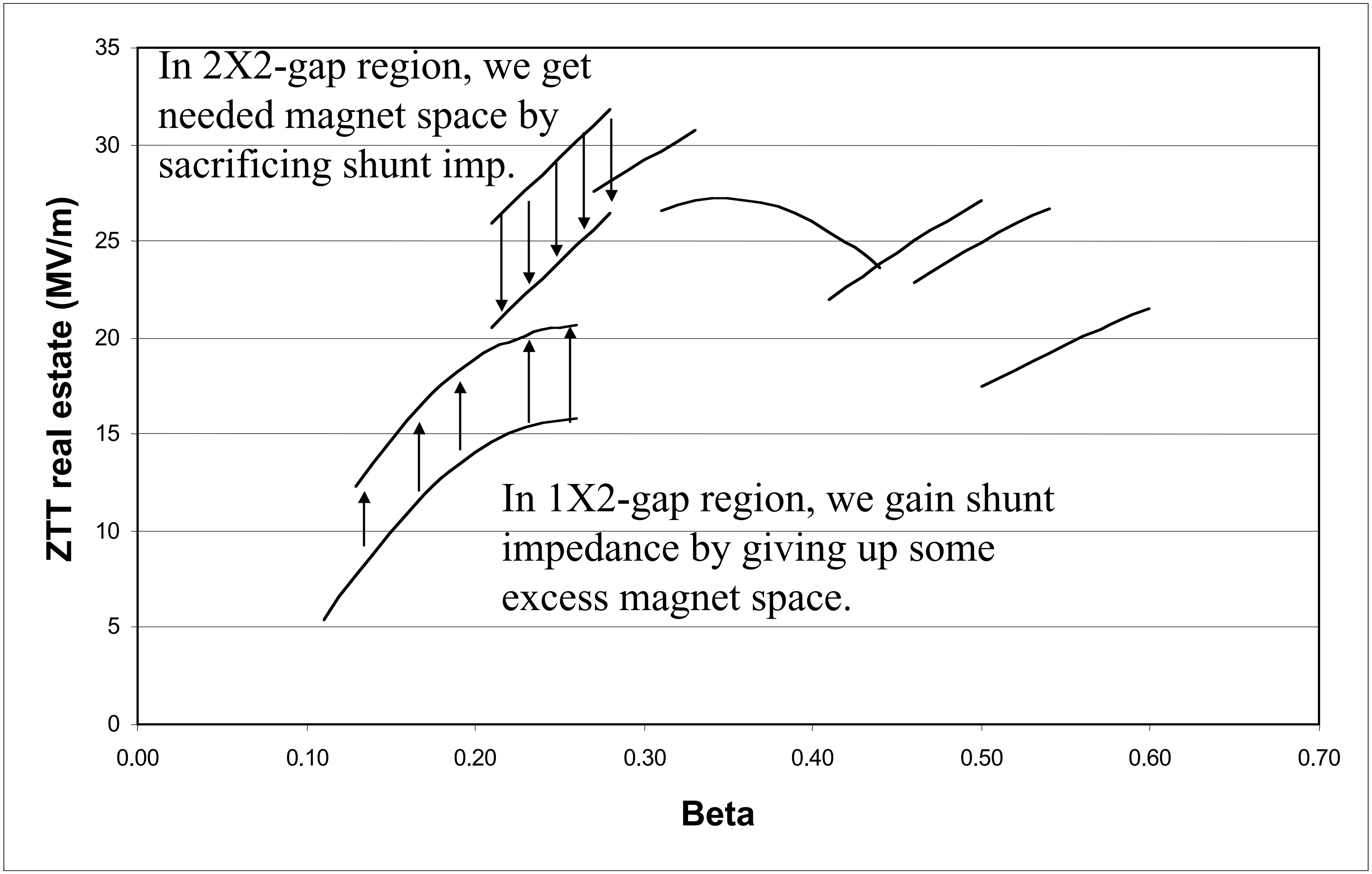


Made possible by cooling improvements in CCDTL.

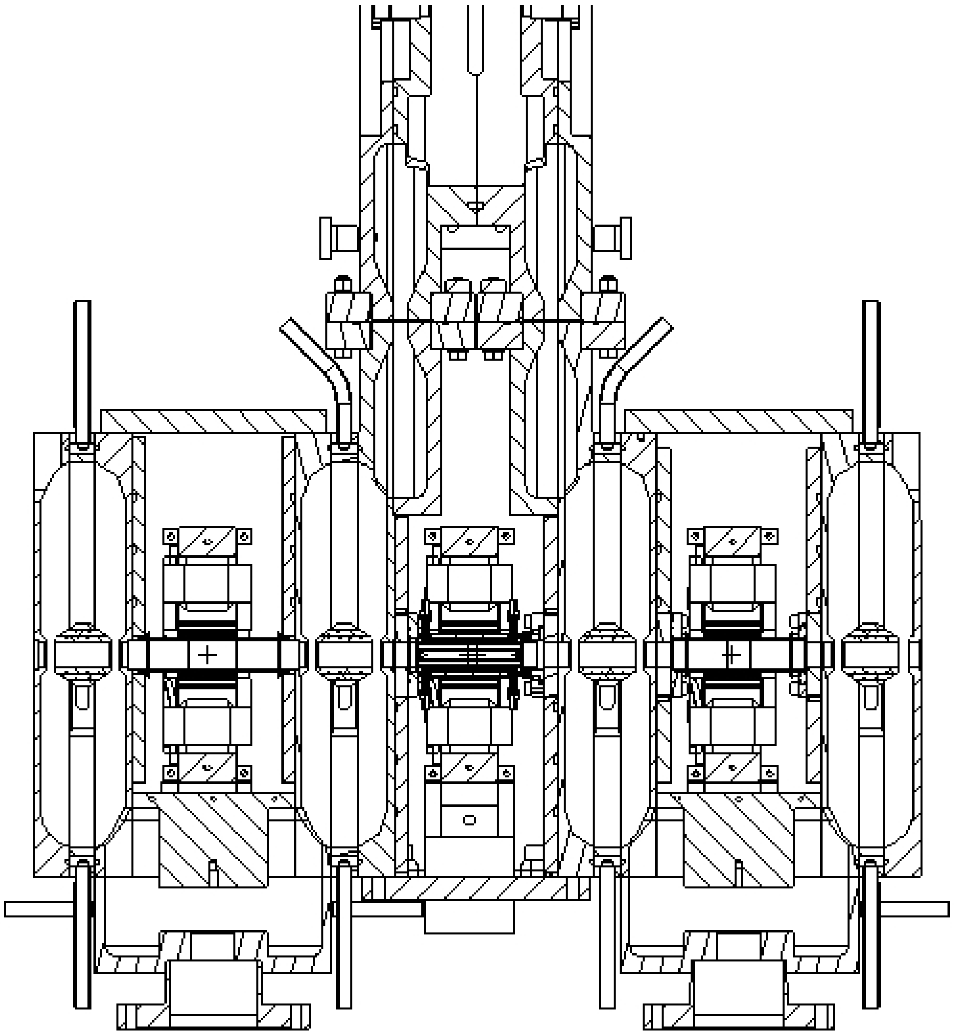
Downside of 8__ lattice is tighter magnet/BPM clearance.



Improved cavity designs strive for better efficiency, clearance for magnets & diagnostics.



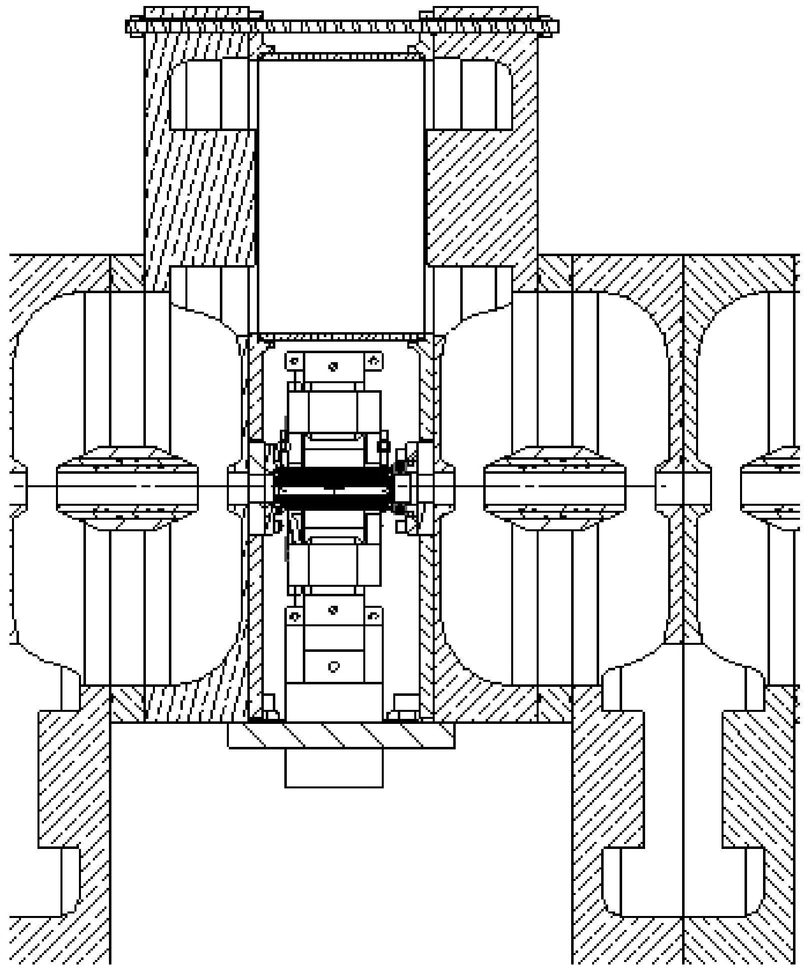
In the 1X2-gap CCDTL, the tightest spot is at the first BPM location, at ~7 MeV.



- BPM design for this location is mature, and clearances are adequate.
- As Beta increases, clearance for magnets and diagnostics increases significantly.

The initial 2X2-gap CCDTL segments are shortened to provide needed BPM clearance.

- 2X2-gap CCDTL now starts at ~37 MeV. First BPM location is shown.
- Shortening the segments penalizes the structure shunt impedance. But the real estate shunt impedance is still very acceptable due to the high packing factor.
- Within 10 meters, _ is significantly higher, allowing return to normal cavity aspect ratio, and better efficiency.



ADTF LEL Beam Dynamics

Bob Garnett

Update on recent ED&D efforts related to CCDTL and CCL

AAA

- CCDTL Low-Beta Hot Model (LBHM) high power test results, analysis, conclusions
- Improvements in higher Beta CCDTL cooling.
- Other miscellaneous.

Coupling cavity overheating is leading suspect for detuning in the CCDTL Low-Beta Hot Model

AAA

FY00 Recap -

- During high-power tests, the CCDTL LBHM suffered significant, permanent drop in resonant frequency.
- Test data showed high temperatures on the underside of the sideways coupling cavities.
- Data analysis and initial computer modeling suggested coupling-cavity over-temp was root cause of detune, but failed to define the mechanism.
- Cooling passages were added to LBHM coupling cavities. This markedly reduced the peak temperatures. But little additional detuning was seen, even with the coolant turned off to these passages. The damage had already been done, and it was impossible to recreate the initial fault conditions.

Thorough FEA effort completed in FY01.

Finite-element analysis (by AES using ANSYS):

¥ Showed plastic deformation in the vicinity of the coupling slots due to coupling cavity overheating.

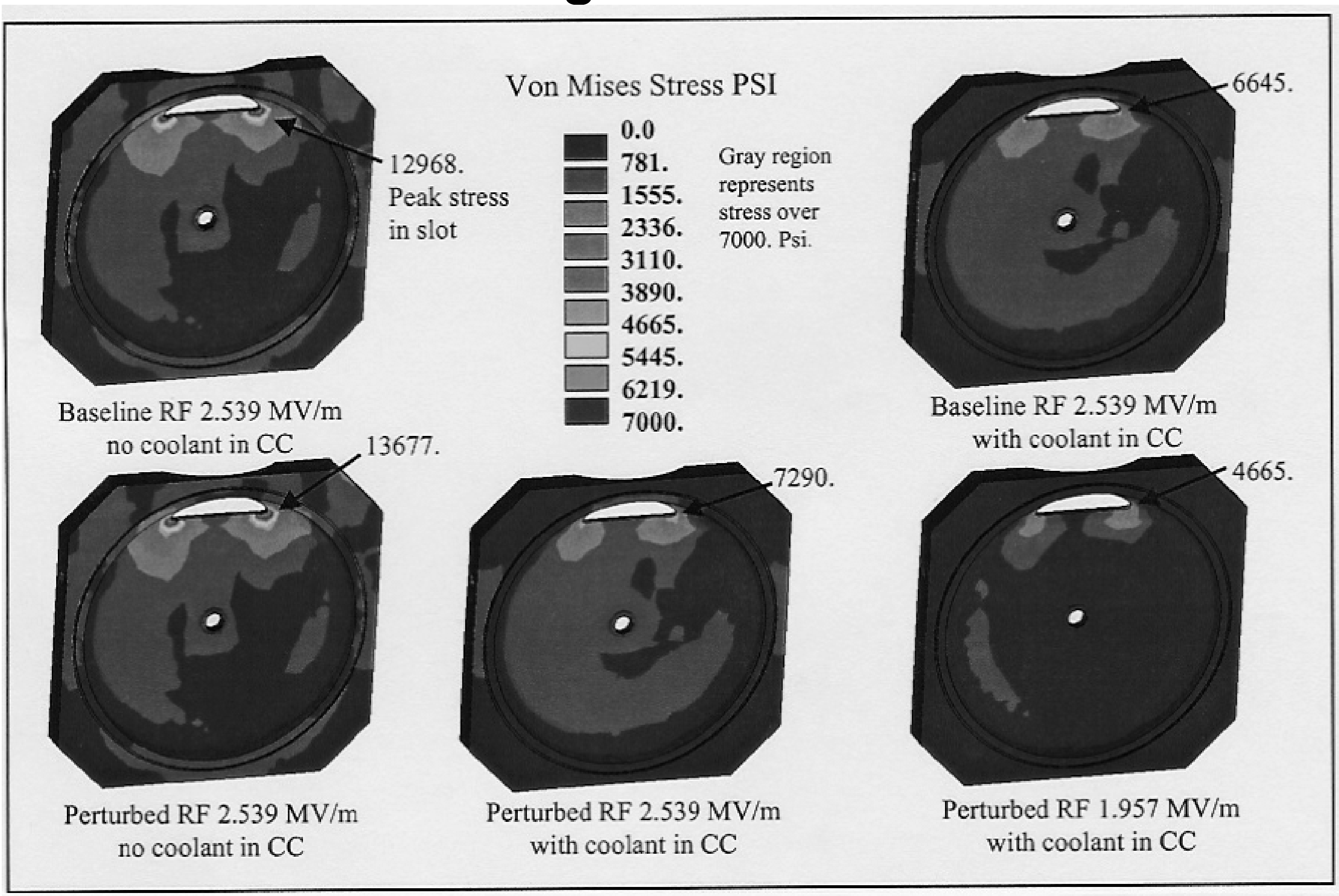
¥ Showed that plastic deformation at the coupling slot can allow slight inward motion of cavity noses. (Biased inward stress due to atmospheric pressure.)

¥ However, the predicted amount of detuning was much less than that observed in the LBHM test.

¥ The significant analysis difficulty and uncertainty is in determining the proper amount and distribution of power dissipation in the coupling cavity.

¥ Results later corroborated by independent FEA efforts at LANL.

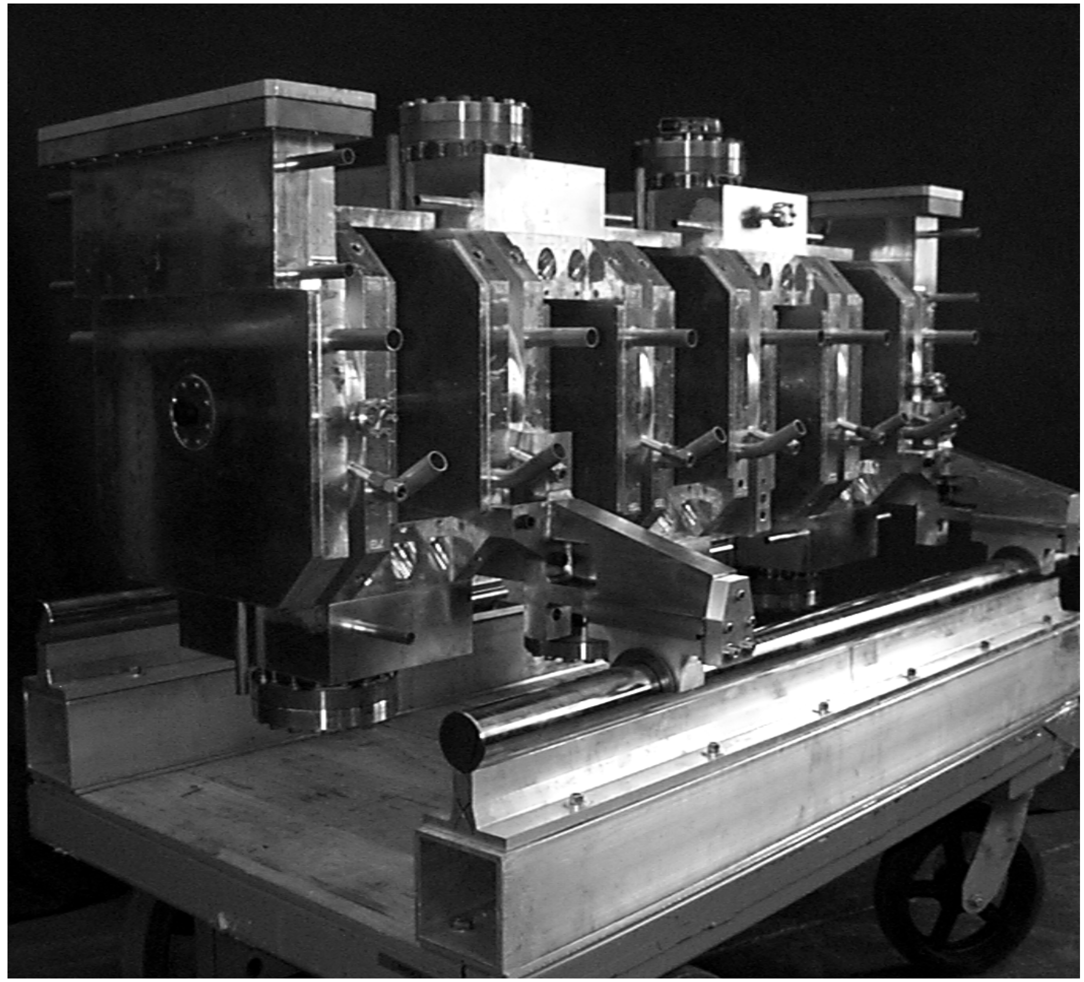
Finite-element RF, thermal, structural, and Slater perturbation analysis shows probable cause of detuning in Low-Beta Hot Model



Hot Test of LEDA CCDTL Section 2 will put several issues to bed.

AAA

- Cooling channels in coupling cavity, plus thicker end walls expected to eliminate the overheating/ detuning problem.
- Hot RF stop-band and heat-transfer measurements will help set realistic cooling requirements, improve cooling designs.
- Shake-down of Resonance Control/ Cooling System hardware and logic.



New LEL design takes advantage of advances in heat transfer understanding.

AAA

¥ LANL conducted heat transfer experiments on prototype 100 MeV drift tube in Fall 00.

¥ Results show that effective heat transfer rates exceed those predicted by published correlations for convective heat transfer in long, straight, circular tubes. Improvement was 2X-3X. (CCDTL drift tube coolant passages are not long, not straight, and not circular.)

¥ The higher E_0T in the new design requires an enhancement factor of only 1.5. In addition, we still have 10-15¡F control margin. So proposed design is still conservative.

More ED&D results (from the CCDTL perspective.)

- ¥ LEDA Halo experiment utilized the CCDTL electromagnetic quadrupoles. Good performance validates the EMQ design, and the straight-rail/pre-alignment concept and methods.
- ¥ Modeling and analysis (GA) of long CCL inter-segment coupling cavities suggests interference by nearby modes. Issue not yet resolved, but it may require use of multi-cell bridge coupler.
- ¥ Design and cold model testing (GA) of a prototype U-shaped waveguide bridge coupler for use with the 1X3-gap CCDTL was completed and formal report made. (But 1X3-gap CCDTL is being eliminated from the plan.)

ADTF NC Low-Energy Linac.
What remains to be done?

Several crucial ED&D items remain to be completed

- ¥ High power thermal testing of LEDA Section 2.
- ¥ LEDA CCDTL 100 mA beam operation.
- ¥ Improve power coupling options for 2X2-gap CCDTL.
- ¥ Design, fabrication, and high power testing of 100 MeV 2X2-gap CCDTL engineering prototype.
- ¥ Finalize the beam-dynamics analysis/design, minimum coupling requirements, and cavity dimension specifications for the rearranged ADTF LEL.
- ¥ Thorough analysis of structure/cooling system thermal response to RF trip; estimate times for beam recovery.
- ¥ Engineering prototype of CCL segments and inter-segment coupling cavity details.
- ¥ Miscellaneous mechanical features and tuning procedures development, validation.

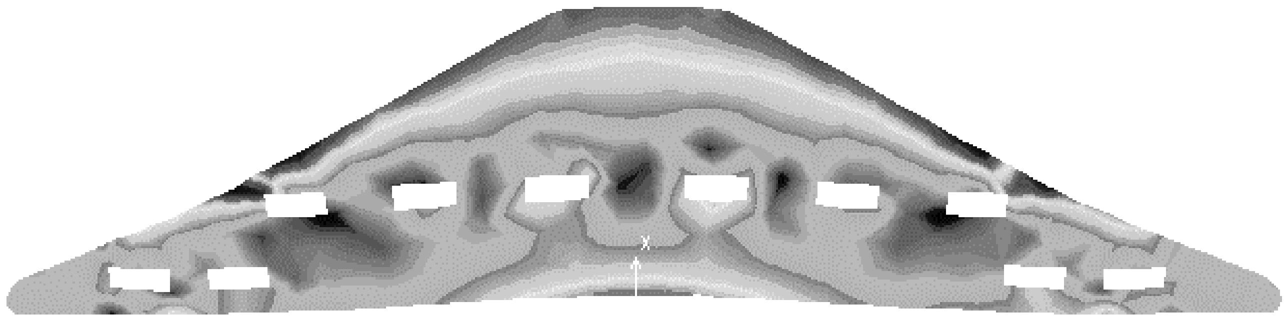
AAA

Low-energy end of CCDTL is now in critical experiment stage

- ¥ **Section 2 Hot Model.**
  - —Final preparations for high-power test of LEDA CCDTL Section 2 are underway. Tests to be completed by 9/2001.
- ¥ **LEDA CCDTL 100 mA beam operation.**
  - —LEDA Sections 1 & 2 plus bridge coupler on-schedule to be ready for installation starting 9/2001.
  - —In-tunnel auxiliary systems are mostly incomplete and have little or no FY01 funding.
    - ¨ resonance control/cooling system
    - ¨ vacuum system
    - ¨ beam diagnostics
    - ¨ controls & DAQ
    - ¨ 700 MHz LLRF

Development of higher energy CCDTL details is crucial to completing the LEL design

- Highest power densities in the LEL occur are on the last CCDTL drift tubes. (@100MeV)



- Cavity resonant frequency and transit-time factors are very sensitive to average drift tube temperature (size) and temperature distribution (distortion).
- Large cavity size means high stored-energy. High coupling factors are difficult to achieve.

Return to the original 8__ lattice eliminated many problems, but revived some dead ones.

¥ Primarily, we get rid of problematic oblong coupling cavity. (Competing resonant modes. Low coupling factors. Very difficult fabrication, cooling, and tuning problems. Others too numerous to list.)

BUT -

¥ Also lost the simple bridge couplers, which housed the waveguide power feeds. Now must couple RF power directly to the accelerating cavities.

¥ Iris-to-accelerating cavity is established option.

—significant tuning effects with competing geometric factors

—cooling complications

—complicates fabrication and tuning sequence

¥ Promising alternatives exist, needing investigation.

AAA

Necessary tests of higher-energy end of 2X2-gap CCDTL are on hold

¥ 100 MeV CCDTL prototype and high power testing is essential before this design can be called complete .

¥ Limited cold modeling was started in FY99-00 (at AES), primarily to examine the oblong coupling-cavity that occurs in the old 9__ lattice design.

¥ Plans for copper fabrication and testing were postponed due to lack of APT funds and resources.

¥ Already long-delayed, the 100MeV CCDTL development was put in abeyance following APT down-select.

¥ All supporting systems are already in place (the LBHM test stand). If ED&D funding is restored in FY02, the 100 MeV Hot Model could be designed, built, and tested by mid-FY03.

Several other Engineering issues remain to be addressed

AAA

- Mechanical joints and cooling for inter-segment coupling cavities in the 2X2-gap CCDTL.
- Improved tuning methods and procedures for CCL end cells and 2X2-gap CCDTL.
- Module tuning provisions and procedures for direct power coupler iris and driven cavities in 2X2-gap CCDTL and CCL.
- Develop means for module-to-module vacuum isolation in 2X2-gap CCDTL.

Incremental Cost & Possible Duration

(Not comprehensive. Only direct CCDTL/CCL costs included.)

	Status (4/2001)	Possible Start/ Restart	Possible Completion	FY02-03 Loaded Cost
CCDTL Section 2 Hot Tests	Final Tuning	Jun-01	Sep-01	na
LEDA CCDTL Operations				
Sec 1&2 installation	On schedule	Sep-01	Dec-01	$400k
Cooling System Redesign	On hold	Apr-01	Oct-01	$130k
Cooling System fab/installation	On hold	Oct-01	Mar-02	$500k
Vacuum system design	95%		soon	$62k
Vac. Sys. parts, assy., check.	On hold	Oct-01	Mar-02	$425k
Low-Level RF system	50%	Apr-01	Jan-02	$400k
Beam Diagnostics design	50%, holding	?	45 weeks	$1200k
Integration and check-out		Apr-01	Apr-02	$650k
CCDTL Commissioning & Operation		May-02	LEDA Operations Budget	
100 MeV Prototype	" abeyance"			
Power coupling Cold Models	" abeyance"	Oct-01	Mar-01	$400k
Design, Fabricate, & Tune	" abeyance"	Oct-01	Sep-02	$3M
High Power Testing	" abeyance"	Oct-02	Mar-03	$1M
CCL Prototype	"abeyance"	y	y+12months	$2M

Conclusions:

- ¥ We have made major progress toward development of a working CCDTL concept, and a NC design for the APT Low-Energy Linac.
- ¥ There are several aspects of the design which have not been given sufficient attention.
- ¥ Recent proposed changes in architecture seek to shorten the list of issues significantly, but there are important details missing.
- ¥ Suspended ED&D tasks must be restarted, and must be thoroughly carried out before this can be called a complete working design.

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

High Energy Linac RF Configurations for the APT-based ADTF Linac

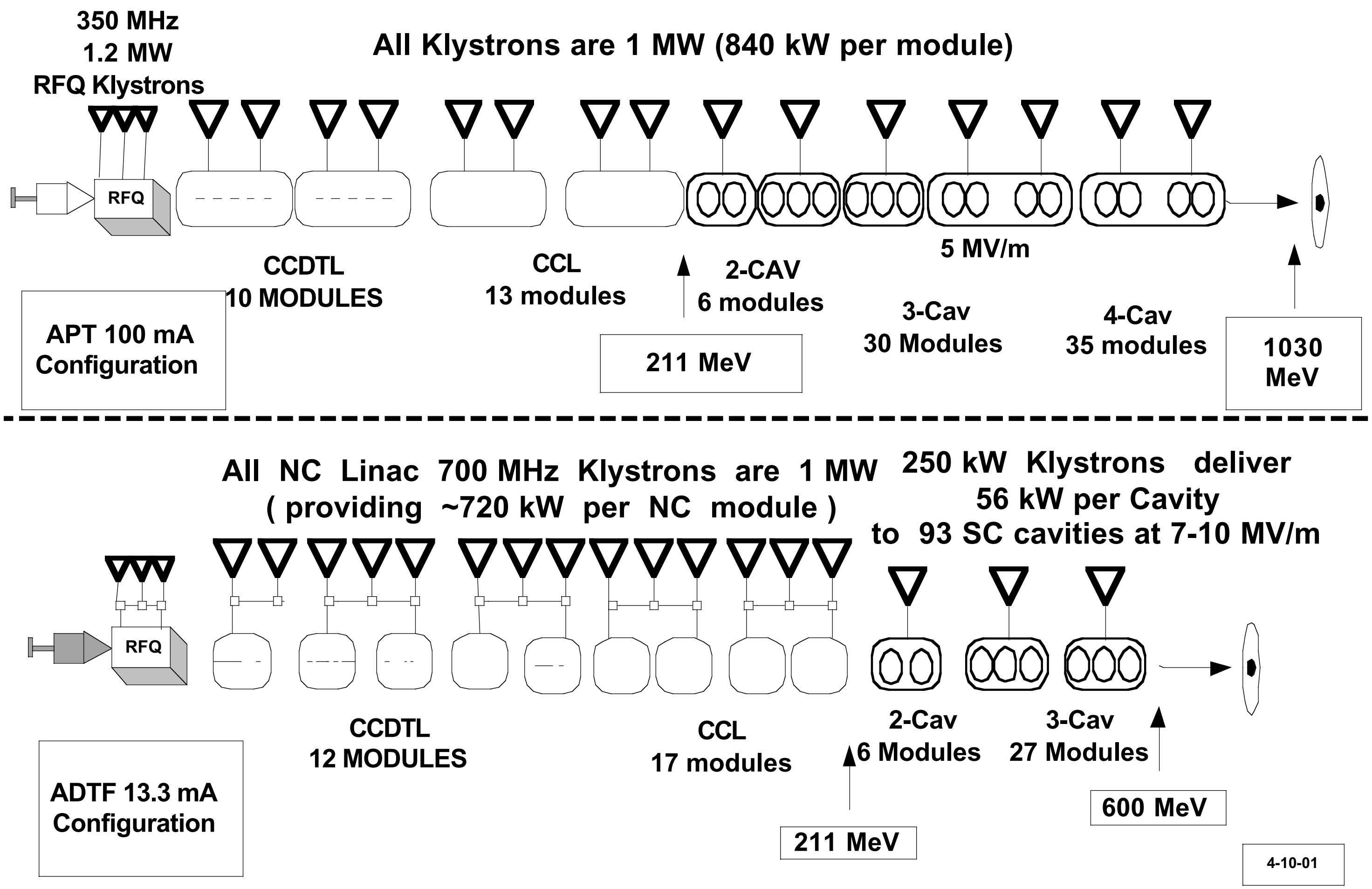
M. McCarthy PPO

Design Considerations

* Utility power grid impact of beam faults.
* Maintenance access and interchangeability by design.
* Increased reliability and control margin by derating klystrons.
* Minimize rf transport loss: waveguide vs coax.
* Minimize component count to increase MTBF.
* Minimize waveguide penetrations to reduce neutron streaming.
* Manufacturing schedules for major rf components.

* **Groundbreaking: 2004**

100 mA APT & 13 mA ADTF Reference Configurations



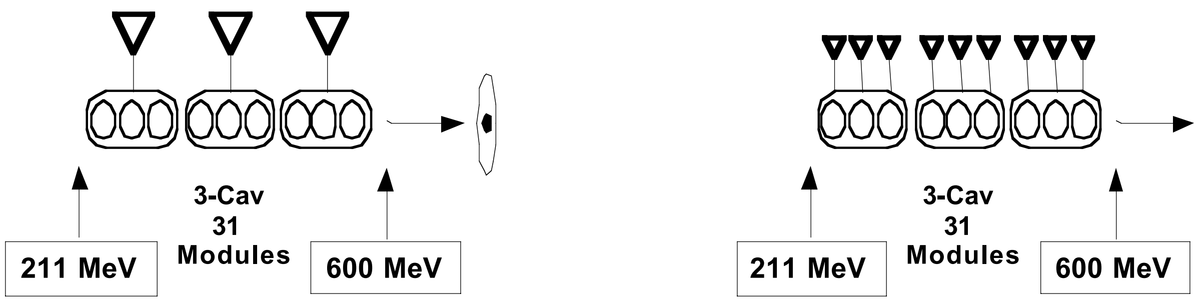
Basis for RF Power Options on High Beta SC Linac

AAA

Table 1-ADTF Strawman S2 Design Parameter Summary		
	ADTF 13.3 mA	APT
	Section 5	0.64 Beta
Structure type	5-cell elliptical	5-cell elliptical
Win,section (MeV)	211	211
Wout,section (MeV)	600	471
Frequency (MHz)	700	700
Betag	0.64	0.64
E0T(MV/m)	7.0489	5
DW/cav (MeV)	3.288 to 4.219	~ 2.55
DW/section (MeV)	389	260
Cavities/cryomodule	3	2(first six), 3
Cavities/section	93	102
Cryomodules/section	31	6 2-Cav, 30 3-Cav
Section length (m)	191.596	211.5
Cav Pwr 13.3mA(kW)	56.1	37.24
Cav Pwr 100mA (kW)	422	280
Cavities per generator	3 or 1	3
Number rf generators	31 or 93	36

13.3 mA ADTF Configuration

Klystrons or IOTs deliver
56 kW per Cavity
to 3-Cav SC module at 7-10 MV/m



*** 700 MHz, 56.1 kW delivered per cavity @ 7-10 MV/m**

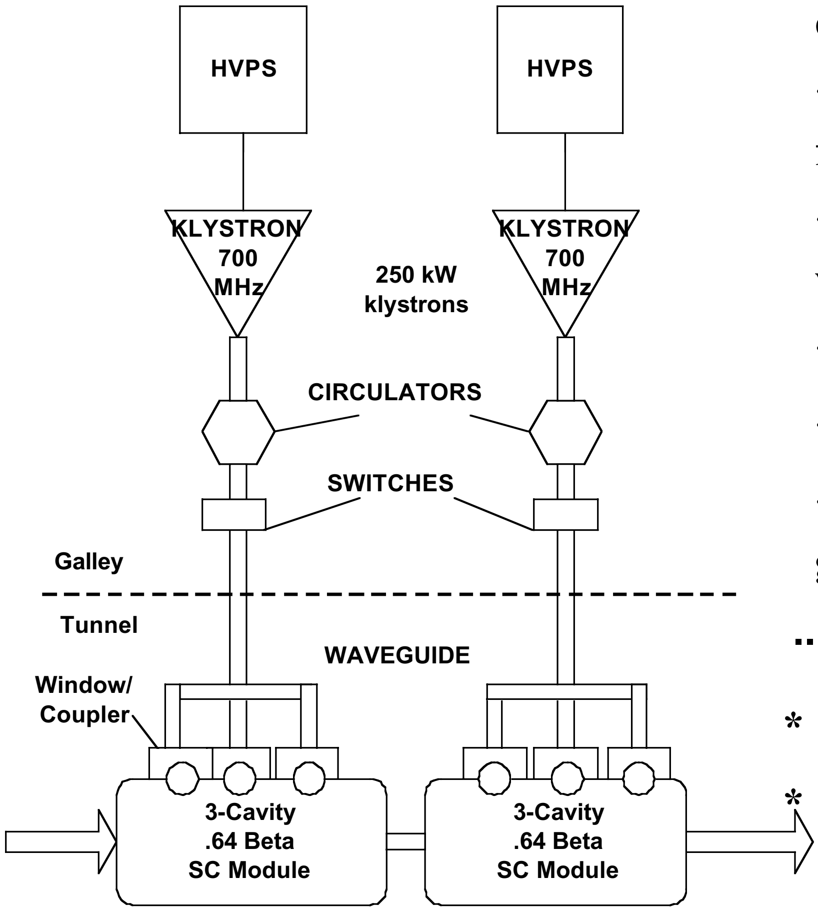
***168 kW per module, plus 12% control margin and 6% loss margin**

*** Add 25% reliability margin: 168kW*1.12*1.06*1.25 = 250 kW**

*** 250 kW per module rf source or 83 k/w rf source per individual cavity**

4-10-01

One 250 kW 700 MHz Klystron per SC Module



* Reduced parts count wrt individual IOT per cavity.

* Sharing HVPS by non-adjacent klystrons is feasible.

* One Conduit per module using full height waveguide in conduit.

* Excellent fault recovery time.

* Low technical risk.

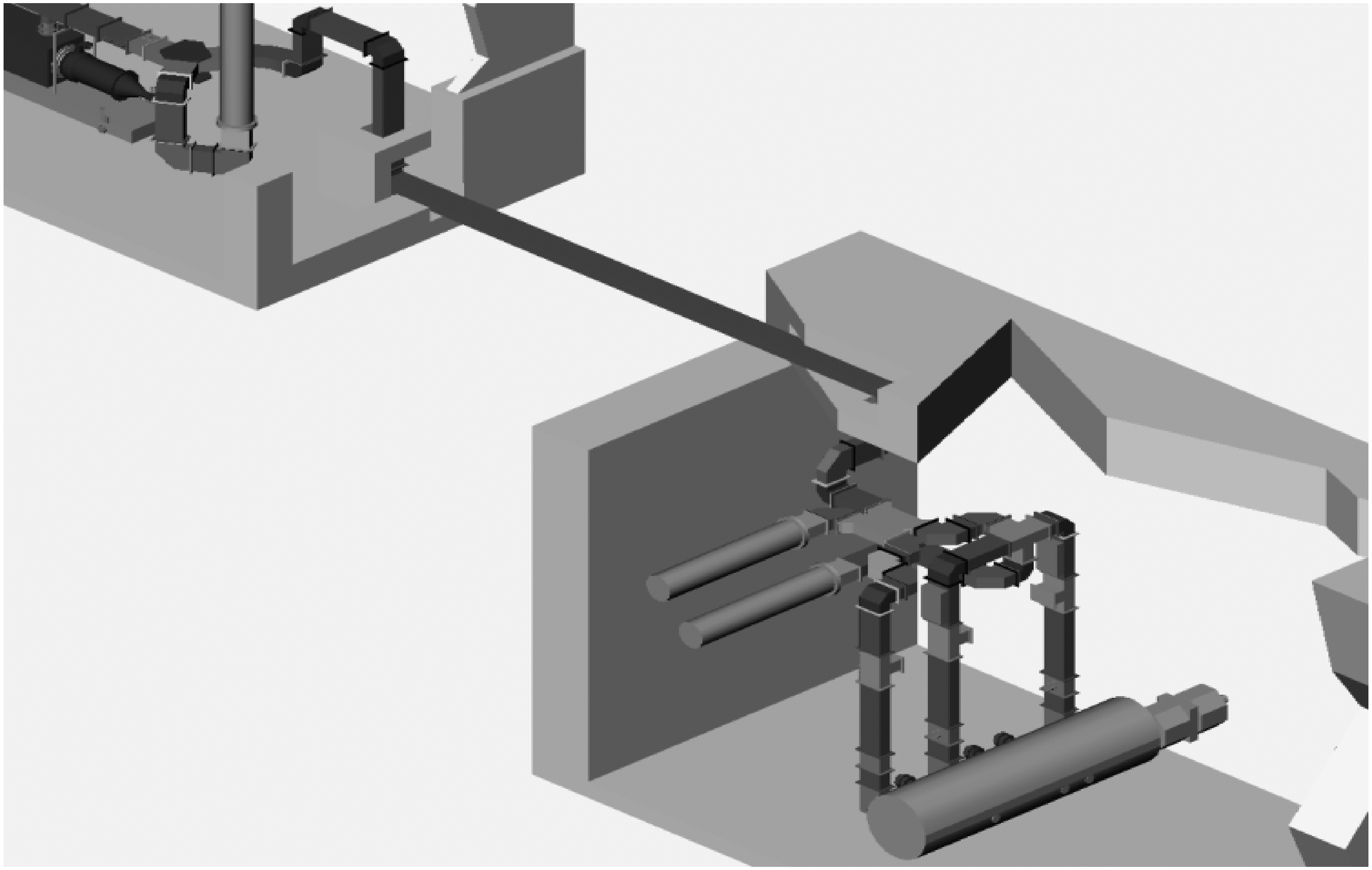
* WG splitters and loads may be moved to the gallery to eliminate need of tunnel access.

....

* Averaged cavity phase and amplitude control.

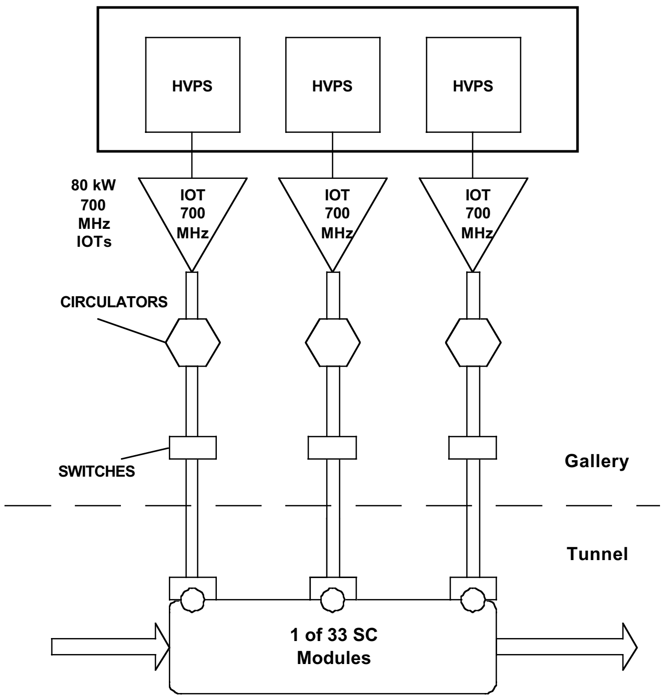
* Waveguide splitter components in tunnel.

One klystron per 3-Cavity SC Module Configuration



Three 83 kW 700 MHz IOTs per SC Module

One IOT per Cavity Configuration

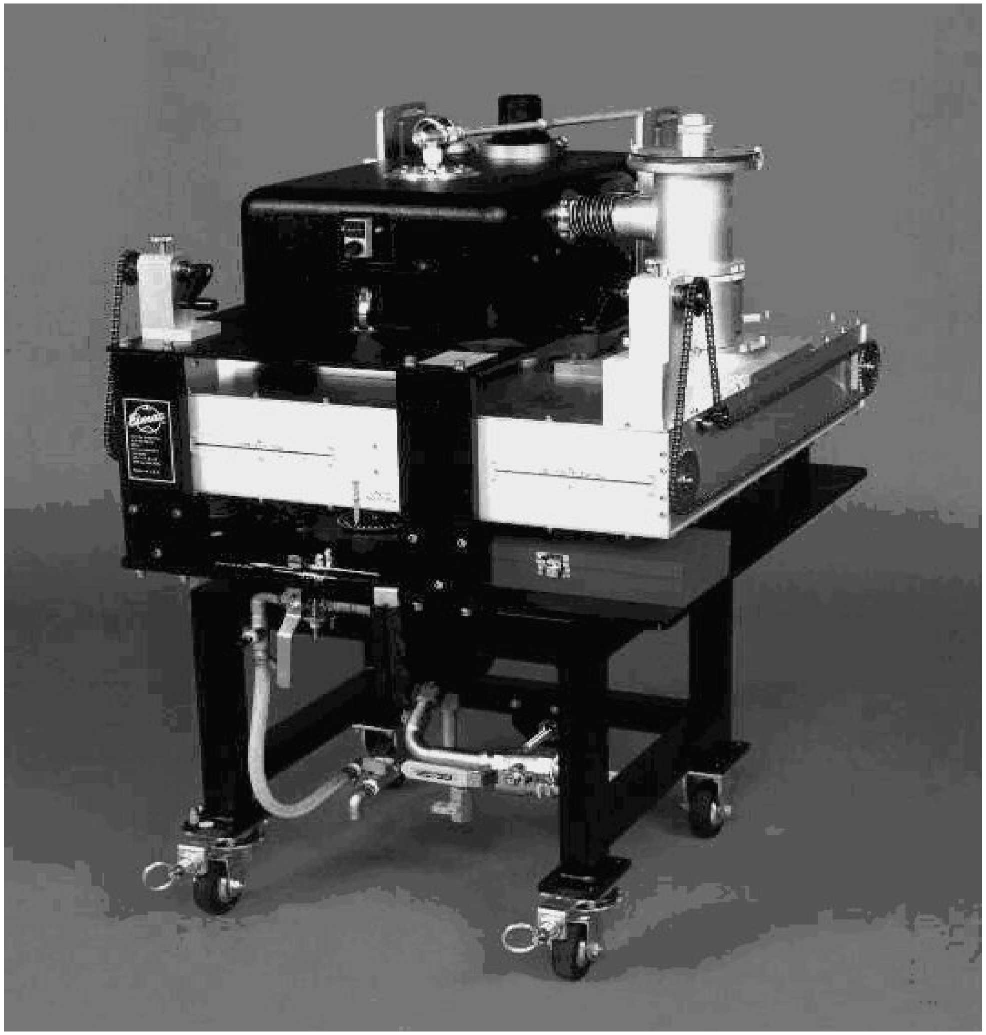


* Individual Cavity Phase and Amplitude Control.
* Reliable and efficient IOT power.
* One HVPS per three IOTs is feasible.
* One Conduit per SC module by using 1/4 Height waveguide in conduit or 6 coax.
* Excellent fault recovery time and impact.
* Reduced X-ray shielding required around IOTs.
* 100 mA operation achieved by replacing each IOT with a 500kW klystron (@ 7 MV/m, no additional SC modules are required).

....

* Nearly three times the amount of RF components per superconducting module resulting in higher cost and complexity per module.
* Some IOT development required.

EIMAC Inductive Output Tube



* 35 kW average output power used for commercial TV.

* Vendor says 150 kW is not a serious technical risk ($800-1200 k development cost).

* Efficiency ~ 70% at all power levels.

* Relatively inexpensive HVPS required. May share one HVPS for multiple IOTs.

*Tube replacement takes less than 10 minutes.

* X-ray shielding requirement is minimal.

TPO-RGN-1003

AAA

RF System Availabiltiy Spreadsheet

One 250 kW RF Source per Cryomodule		13.3 mA capability		
HE Linac RF only	31 Modules			
ADTF Estimate	MTBF	#	MTTR	MEAN TIME
	(HOURS)	RF System	(HOURS)	BETWEEN
No Spares		Component	Beam-Off	FAILURES
Low Energy Only		with spares	time	(HOURS)
Solenoid PS	100000	62	8.00E-04	1613
Solid State Amp Circuit	100000	31	8.00E-04	3226
Klystron Water System	100000	31	8.00E-04	3226
Filament Power Supply	100000	31	8.00E-04	3226
VAC-ION HVPS	100000	31	8.00E-04	3226
IOC & HPP Interface	40000	31	8.00E-04	1290
PLC Controller&Connections	24000	31	8.00E-04	774
HVPS	30000	31	8.00E-04	968
KLYSTRON (250 kW)	50000	31	8.00E-04	1613
CIRCULATOR	60000	31	8.00E-04	1935
Circulator Load	60000	31	8.00E-04	1935
Waveguide/ Water Sys	100000	31	8.00E-04	3226
LLRF	50000	31	8.00E-04	1613
Tunnel Componets				
Magic-Tee Loads	50000	62	4	806
Auto phase shifter	50000	62	4	806
Waveguide/Water System	100000	29	4	3448
RF WINDOW	400000	93	24	4301
Downtime per Runtime Year				
Runtime Year Availability				
Note: MTTR is beam-off time. This is the time it takes to isolate an rf station and bring the bea				
Cost at $3 per Watt installed.		$23,250,000		

ADTF Linac Review, April 10-12, 2001

RF System Availabiltiy Spreadsheet

One 250 kW RF Source per Cryomodule					
HE Linac RF only	31 Modules	# Spares =	0		
ADTF Estimate	MTBF	#	#	#	DOWN
	(HOURS)	FAILURES	FAILURES	FAILURES	TIME
No Spares		PER	< 100 Sec	> 100 Sec	(HOURS)
Low Energy Only		Runtime Year			
Solenoid PS	100000	4.8	0.0	0.0	0.0
Solid State Amp Circuit	100000	2.4	0.0	0.0	0.0
Klystron Water System	100000	2.4	0.0	0.0	0.0
Filament Power Supply	100000	2.4	0.0	0.0	0.0
VAC-ION HVPS	100000	2.4	0.0	0.0	0.0
IOC & HPP Interface	40000	6.0	0.0	0.0	0.0
PLC Controller&Connections	24000	10.0	0.0	0.0	0.0
HVPS	30000	8.0	0.0	0.0	0.0
KLYSTRON (250 kW)	50000	4.8	0.0	0.0	0.0
CIRCULATOR	60000	4.0	0.0	0.0	0.0
Circulator Load	60000	4.0	0.0	0.0	0.0
Waveguide/ Water Sys	100000	2.4	0.0	0.0	0.0
LLRF	50000	4.8	0.0	0.0	0.0
Tunnel Componets					
Magic-Tee Loads	50000	9.6	0.0	9.6	38.2
Auto phase shifter	50000	9.6	0.0	9.6	38.2
Waveguide/Water System	100000	2.2	0.0	2.2	8.9
RF WINDOW	400000	1.8	0.0	1.8	43.0
Downtime per Runtime Year		81.3	0.0	23.1	128.5
Runtime Year Availability					0.9838
Note: MTTR is beam-off time. This is the time		m back to full operation.			
Cost at $3 per Watt installed.					

ADTF HE RF Option Summary

SC Linac Configuration	Beam trips>300 ms, (No. Faults > 300 ms< 100 Sec)	# Faults over 100 sec.	Relative Percent Availability	Relative RF System Cost @ $3.00/Watt (Installed).	Normalized Cost	Notes:
13.3 mA One 250 kW klystron per module	0, (58.2)	23.15	0.984	$23,250,000	1.00	Least expensive.
13.3 mA One 83kW IOT per Cavity	0, (142.2)	2.99	0.994	$25,574,898	1.10	Least faults under 100 sec. Control of individual cavity phase and amplitude.
100 mA One 500 kW klystron per cavity	0, (142.2)	4.18	0.993	$153,450,000	6.60	Path to 100 mA beam. Individual cavity phase & amplitude cntl.
100 mA One 1 MW klystron per cavity	0, (73.5)	24.69	0.983	$144,000,000	5.63	Path to 100 mA beam. 5 MV/m, 448 MeV at cavity 93.

Advanced Accelerator Applications (AAA)

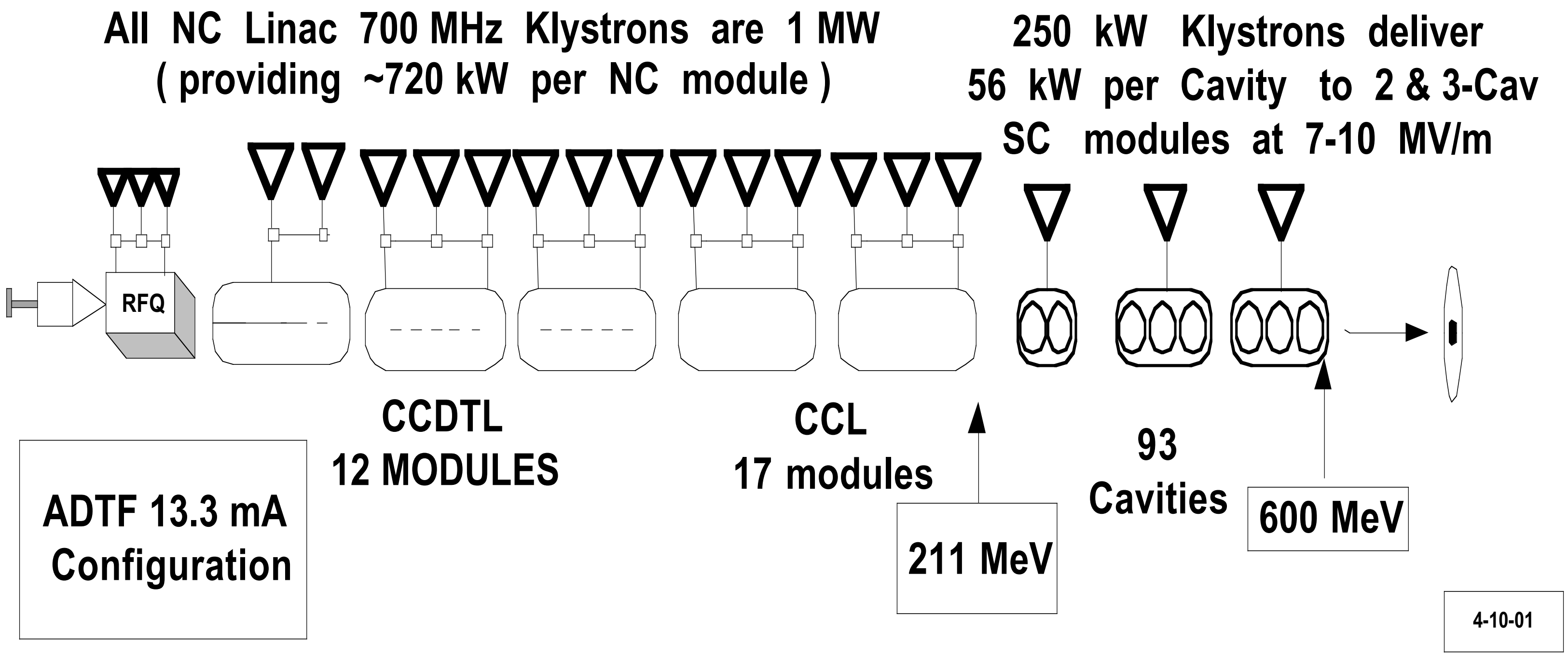
ADTF Linac Design Review

April 10 – 12, 2001

Low Energy Linac RF Configurations for the APT-based ADTF Linac

M. McCarthy   PPO

13 mA Reference RF System

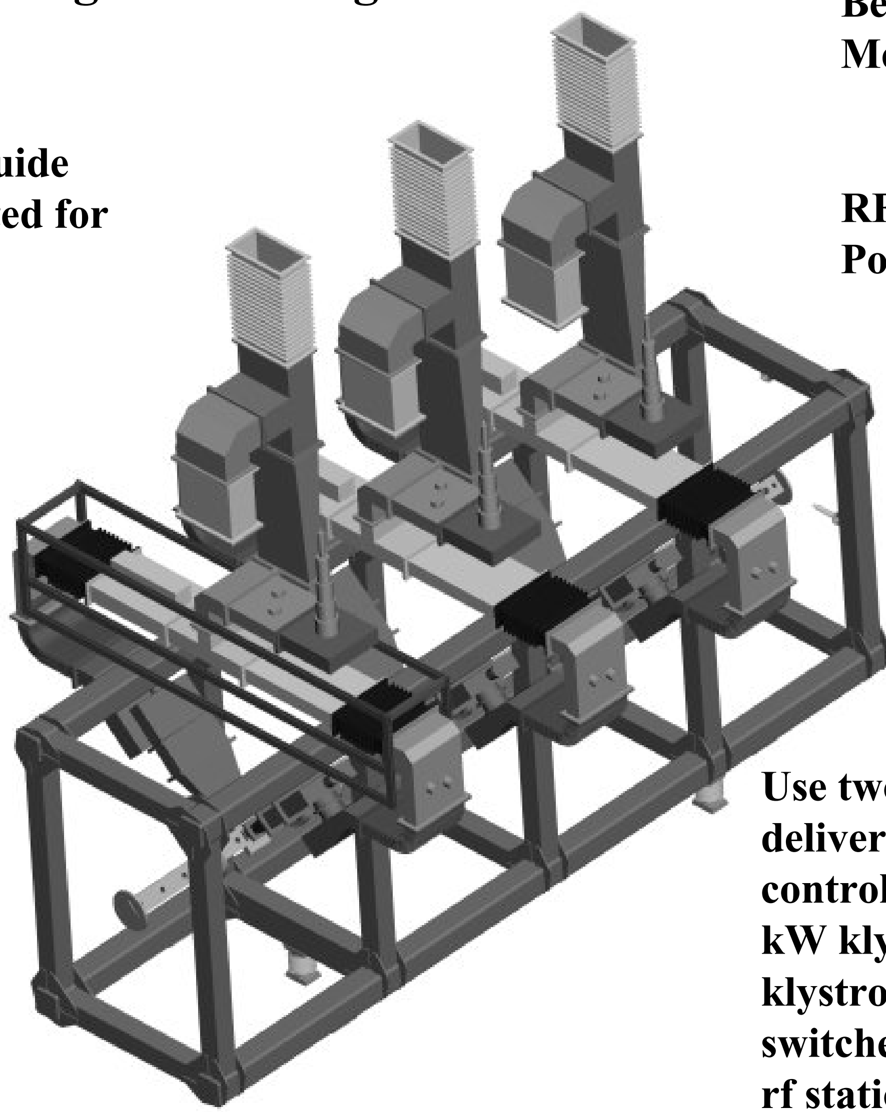


ADTF RF Power Requirements Summary (APT-based Reference System)

AAA

Structure	Freq (MHz)	No. RF Systems	Total RF Required* (MW)	RF Source Size	Utility Pwr Req'mnt (MW)
RFQ	350	3	1.7	1.2 MW	3.1
CCDTL/CCL	700	44	22.7	1.0 MW	39.1
SC Beta = 0.64	700	33 (93)***	9.8	250 kW (83 kW)***	16.9
Totals		80 (140)***	34.2	RF Systems Utility Power Requirement =	59.1
* Includes 6% loss and 12% control margins	** Assumes ~50% klystron efficiency	*** IOT per SC cavity		With SC IOT per Cavity	56.2

RFQ Tunnel Waveguide Arrangement



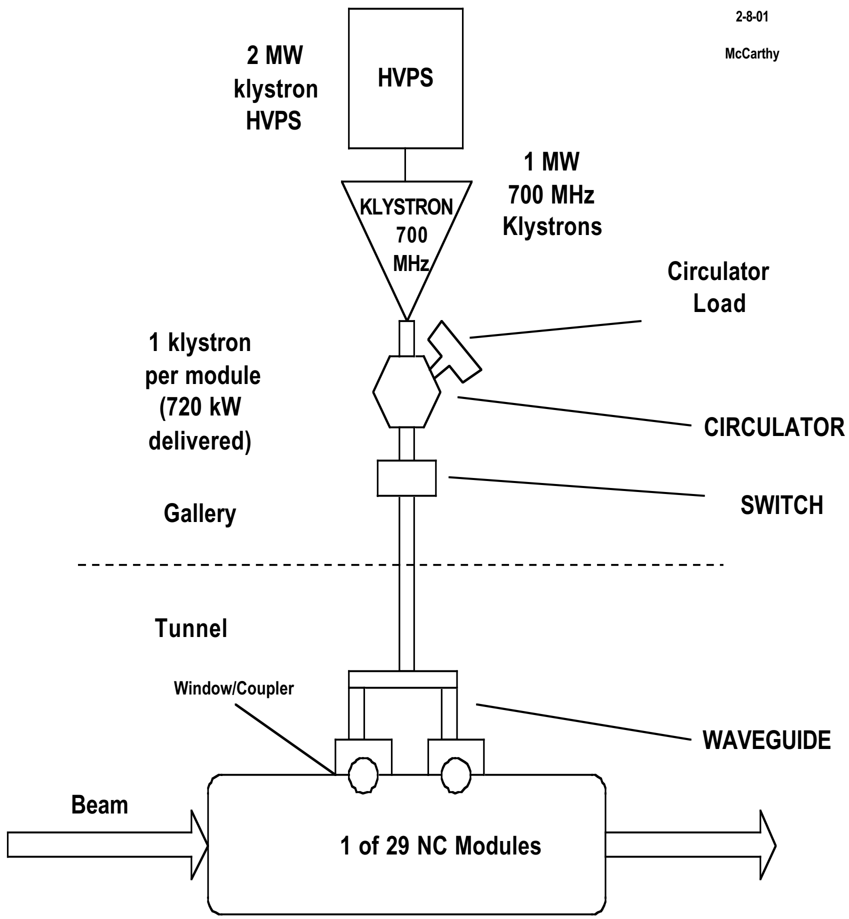
Middle waveguide assembly deleted for ADTF.

Beam Power at 13.3 mA at 6.7 MeV is 89.1 kW

RFQ Cavity Copper Power is 1.33 MW

Use two 1.2 MW klystrons delivering 710 kW (plus control margin and loss = 842 kW klystron output). Center klystron used as hot spare and switched in to replace a failed rf station.

One Klystron per NC Module (29): Option 1



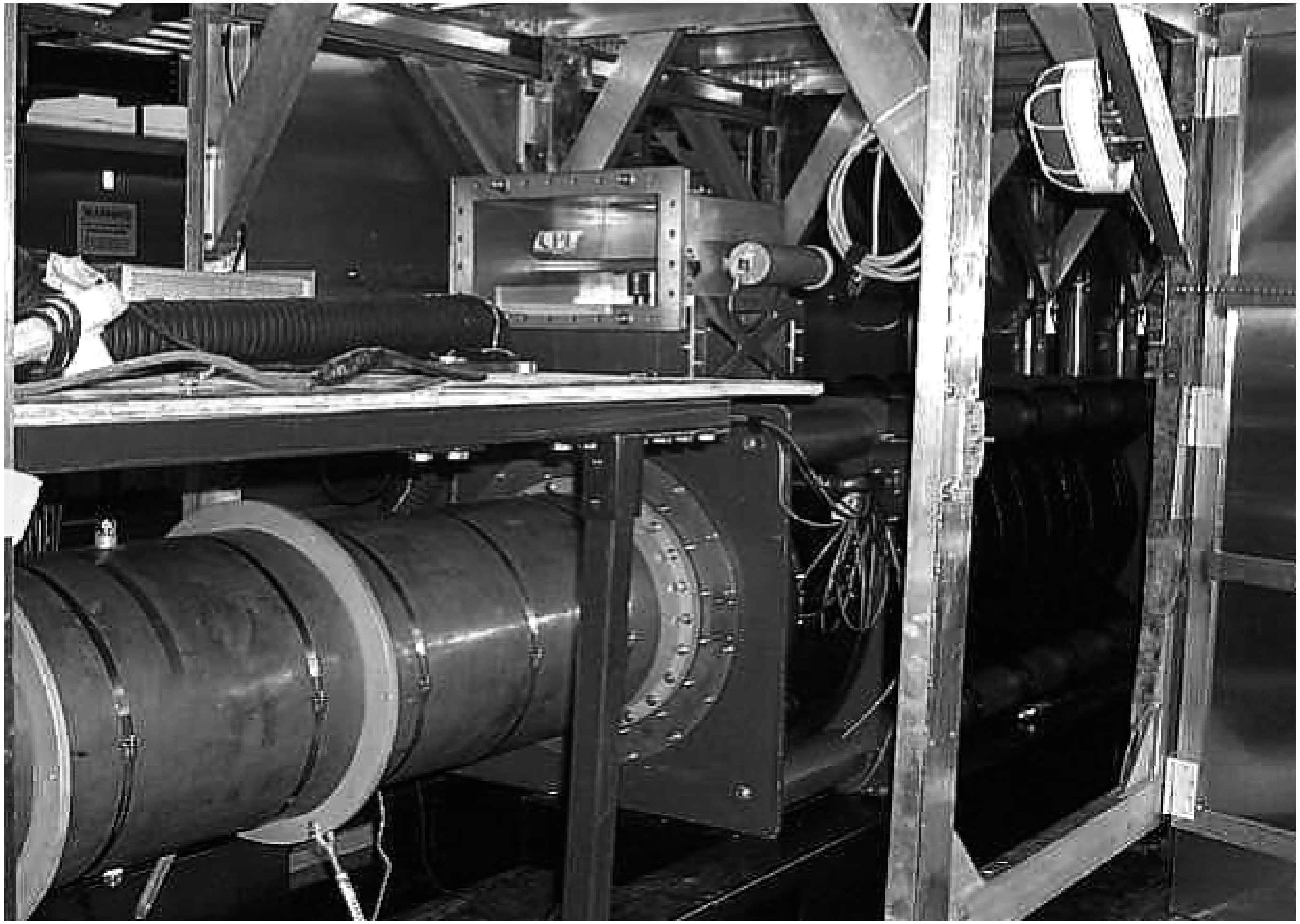
* Low Component Count

* Least expensive

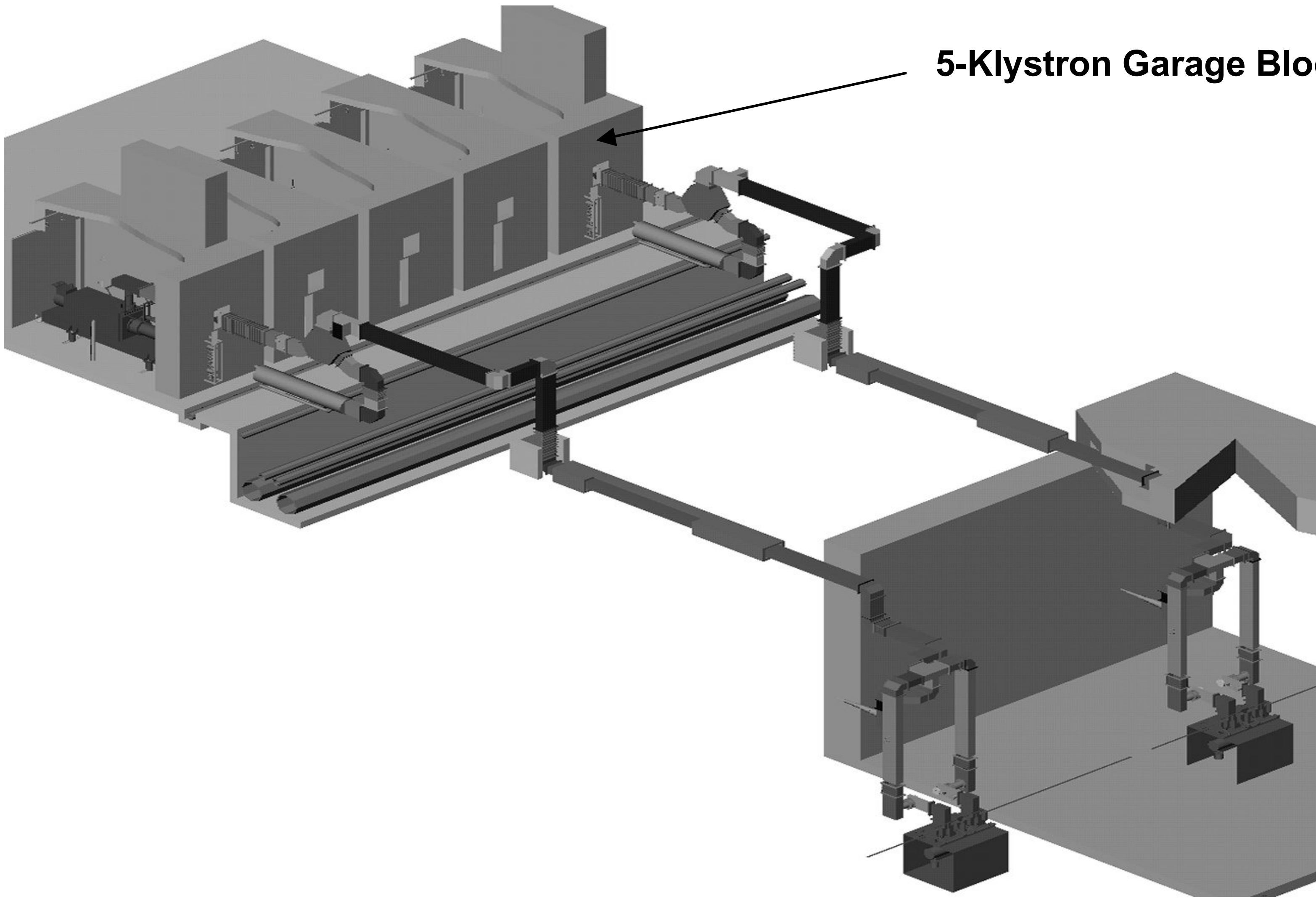
* Splitter and load may be moved to Gallery with use of half-height waveguide in penetration so tunnel access is minimized.

* Any RF Station fault causes beam stoppage until the fault is repaired.

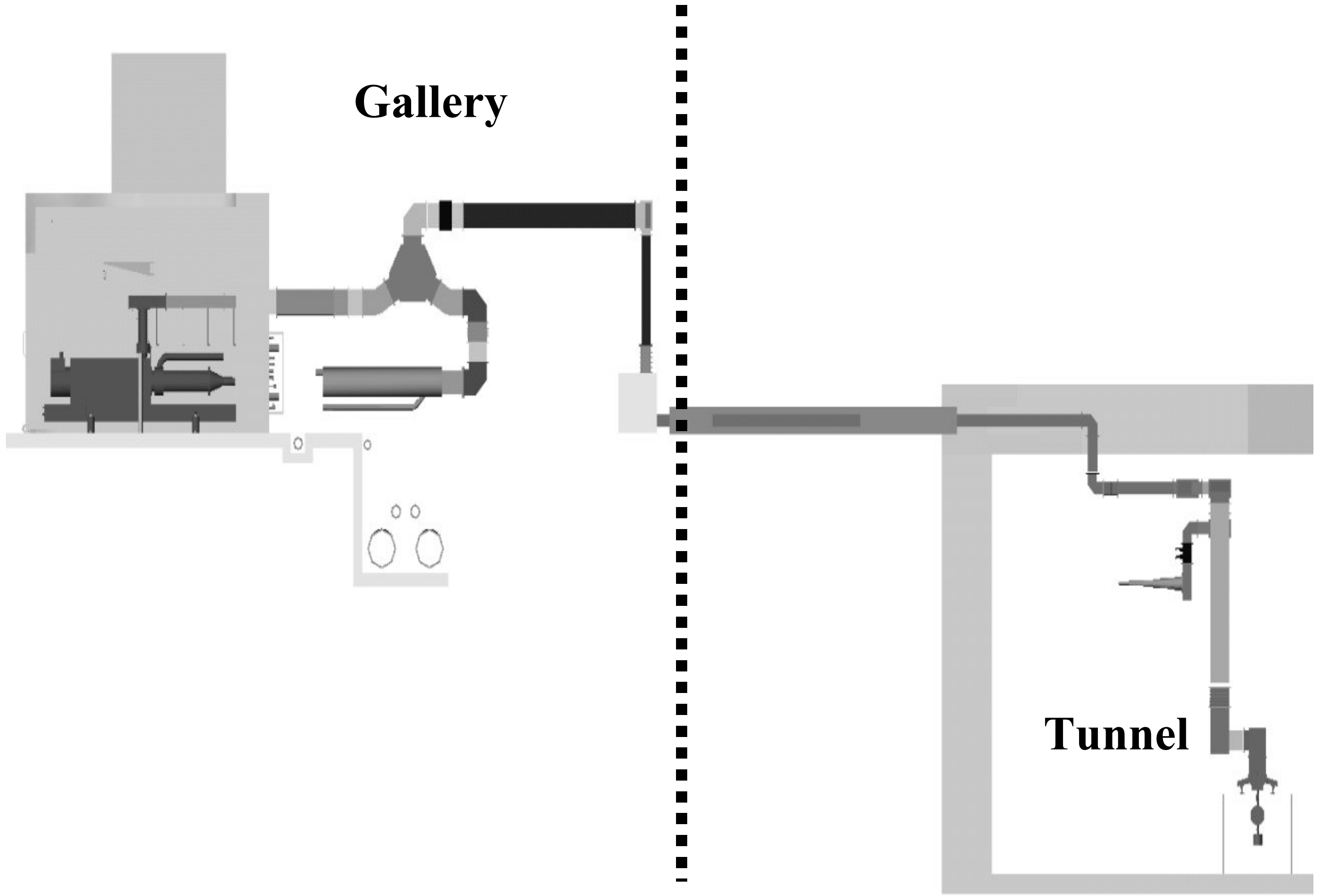
CPI 700 MHz 1MW Klystron in LEDA Lead Garage.



13 mA: One klystron per module, no spare.

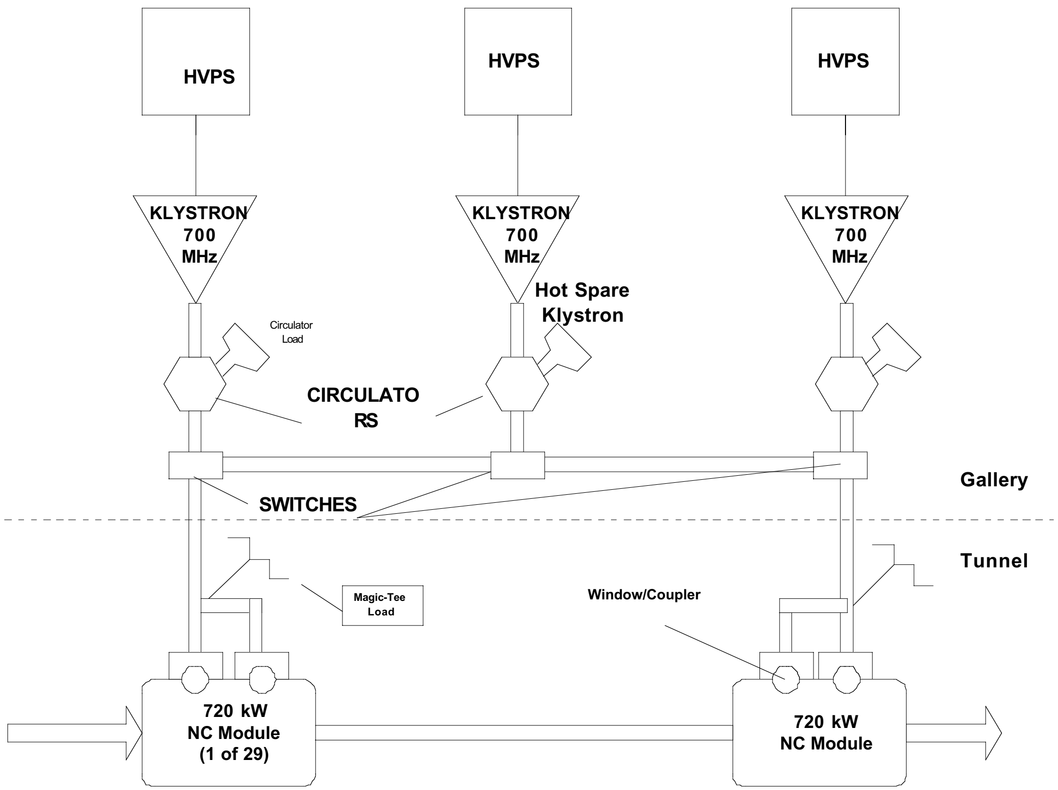


Elevation view: One klystron per module



13.3 mA Single Klystron per NC Module with Spare Reference Design: (Option 2)

AAA



13 mA NC ADTF RF Arrangement

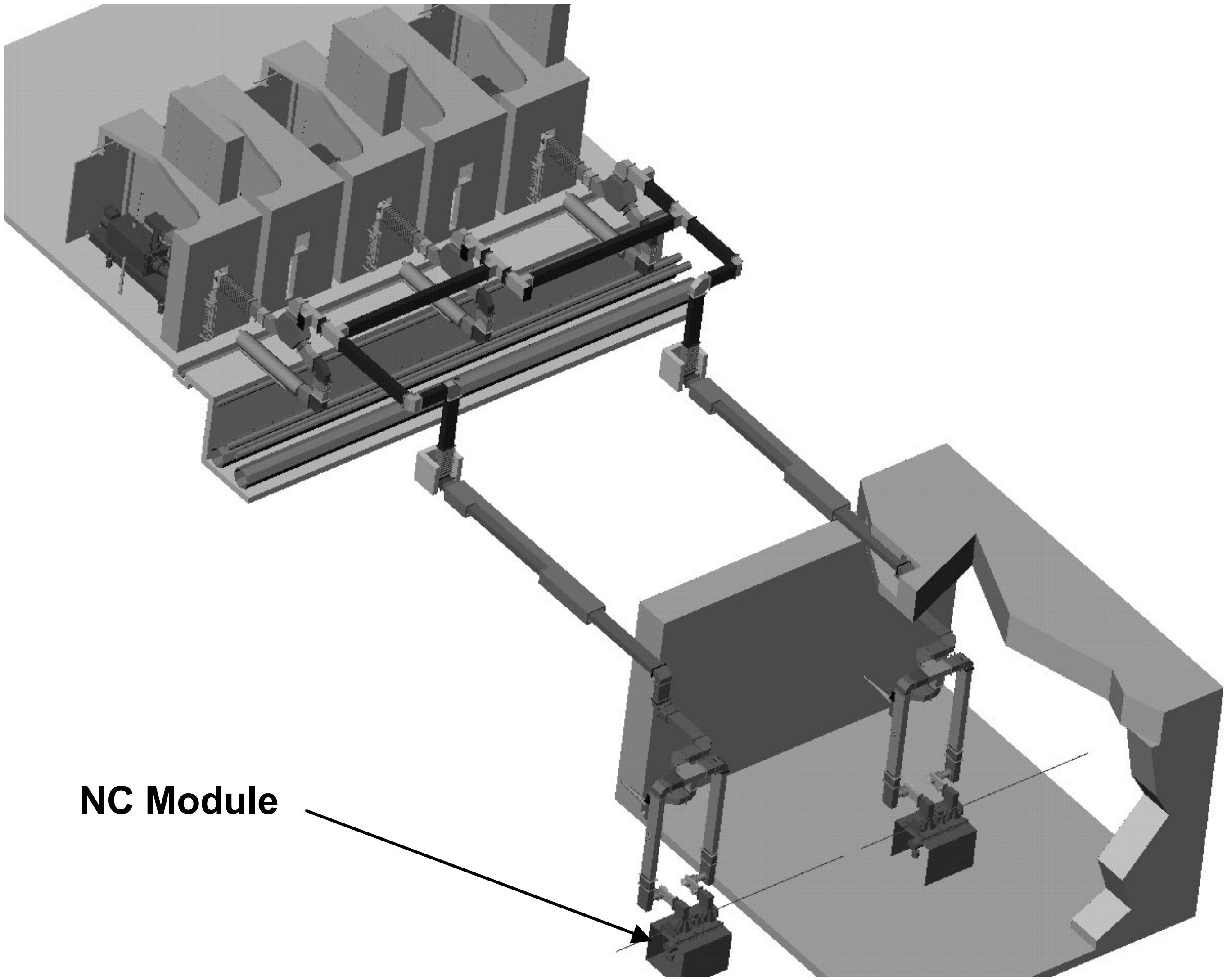
* 2nd lowest parts count.

* RF Station isolated in the time it takes for waveguide switch to close (800 ms).

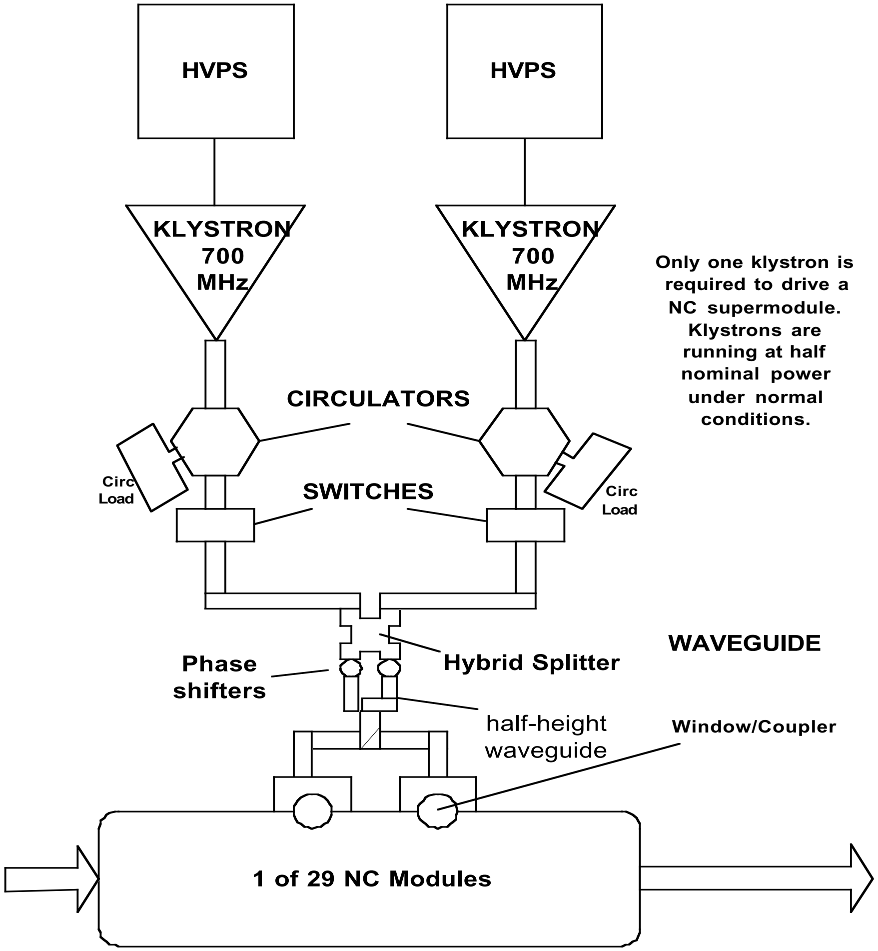
* Waveguide splitters and loads may be moved to gallery to minimize tunnel access time.

* Waveguide switch closure time > 300 ms

13 mA: One klystron per module with center spare.



300 ms Ride Through Configuration: (Option 3)



Only one klystron is required to drive a NC supermodule. Klystrons are running at half nominal power under normal conditions.

WAVEGUIDE

Window/Coupler

* Klystrons running at half nominal power: increased reliability.

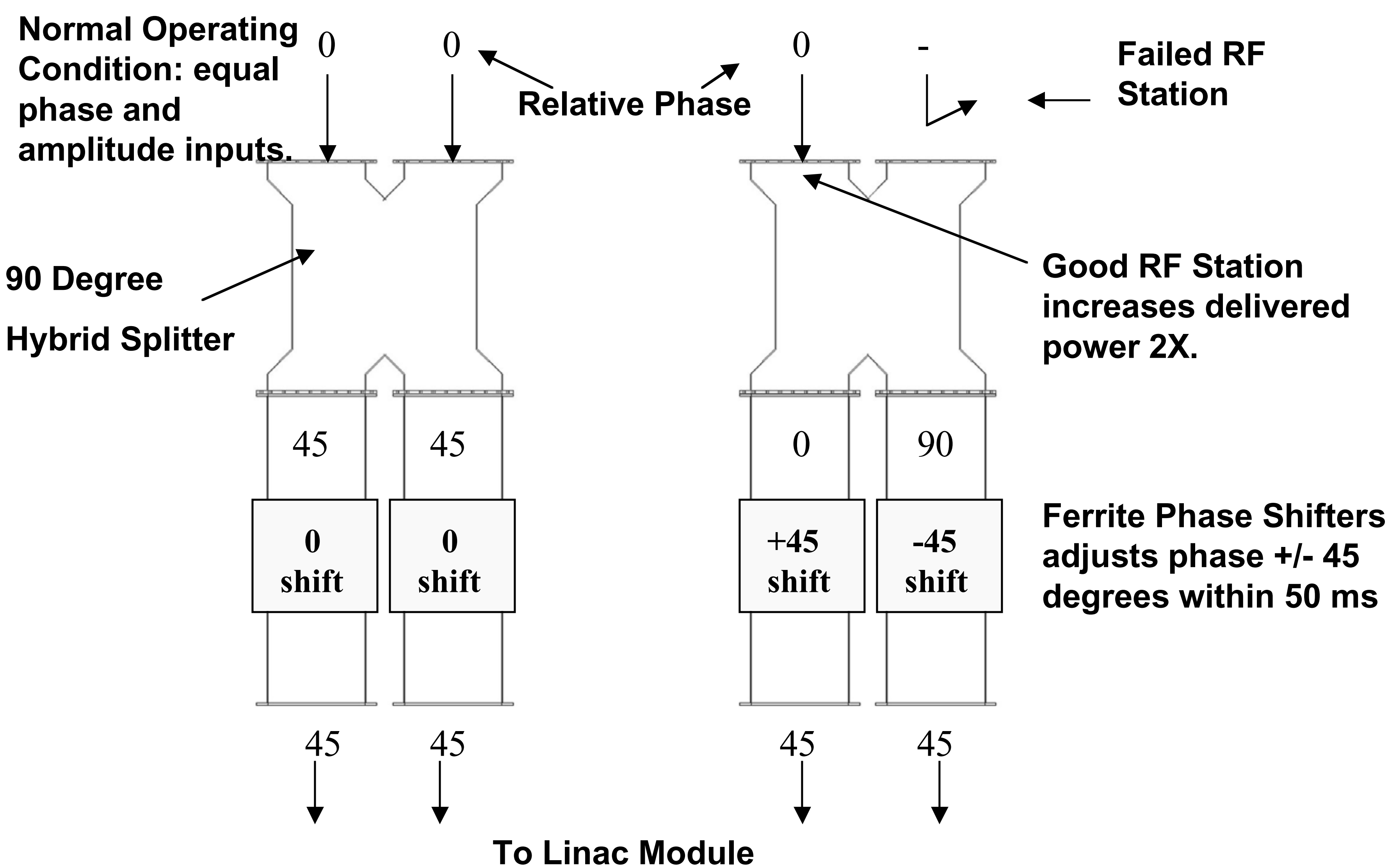
* If RF Station fails, the remaining klystron can continue at full nominal power: beam is off less than 300 ms.

* Failed station can be repaired during beam operation.

* Any waveguide component failure that is common to both RF Stations takes down the beam until repair is completed.

* Requires a reversible master and slave phase and amplitude control arrangement at the hybrid combiner.

300 ms Ride-Through Technique

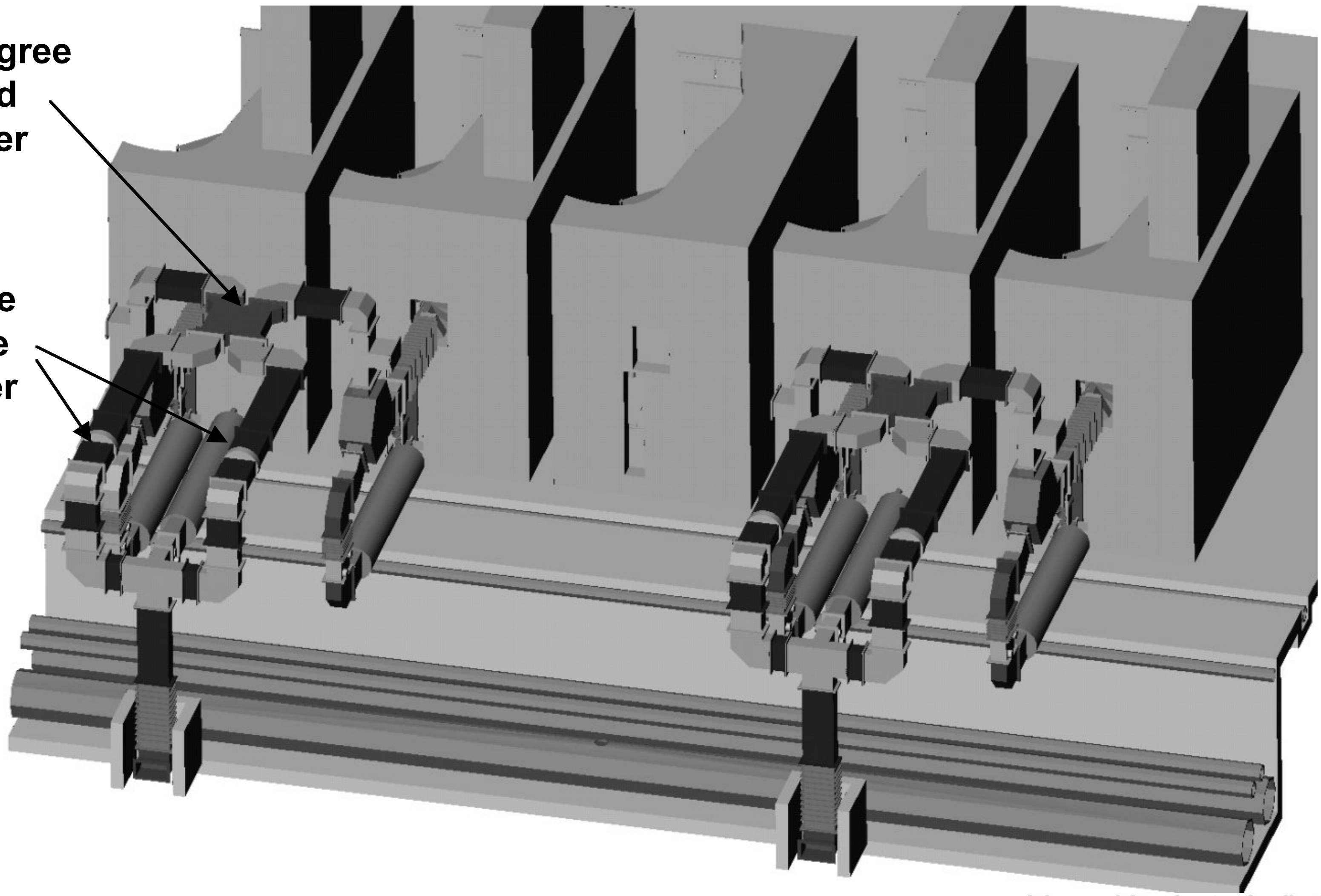


13 mA Ride-Through Configuration

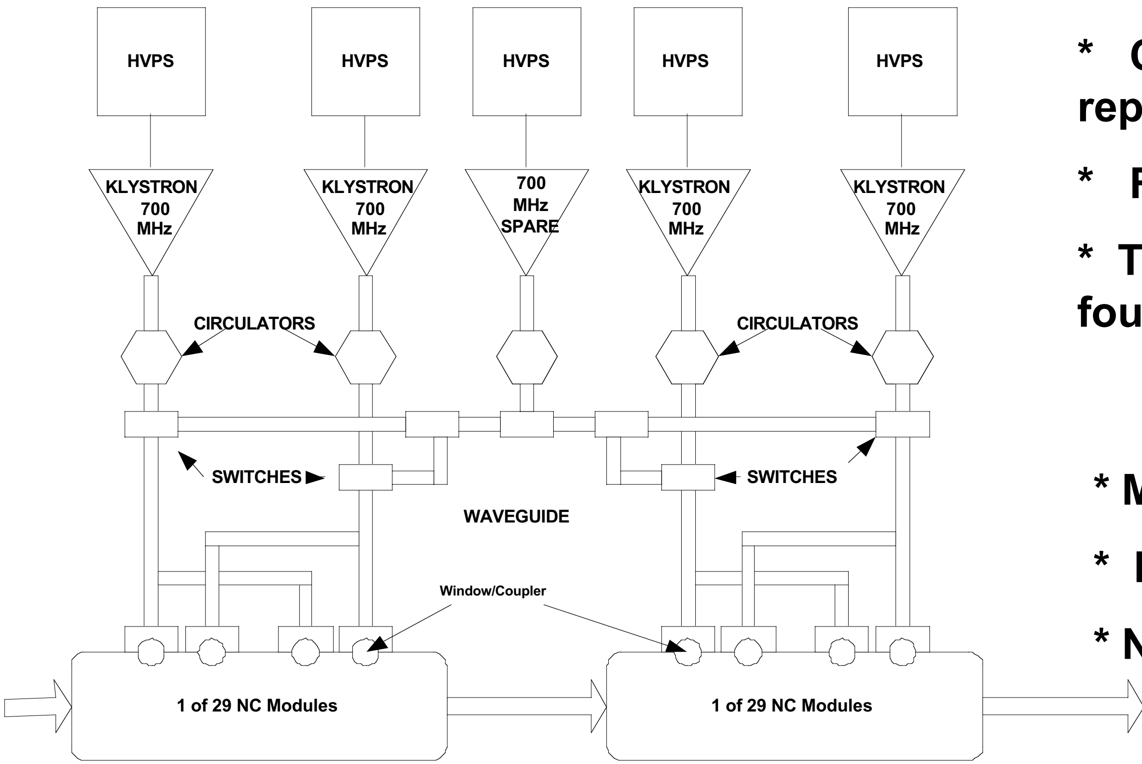
90 degree
Hybrid
Splitter

Fast
Ferrite
Phase
Shifter

t



100 mA upgrade (APT) Configuration: (Option 4)



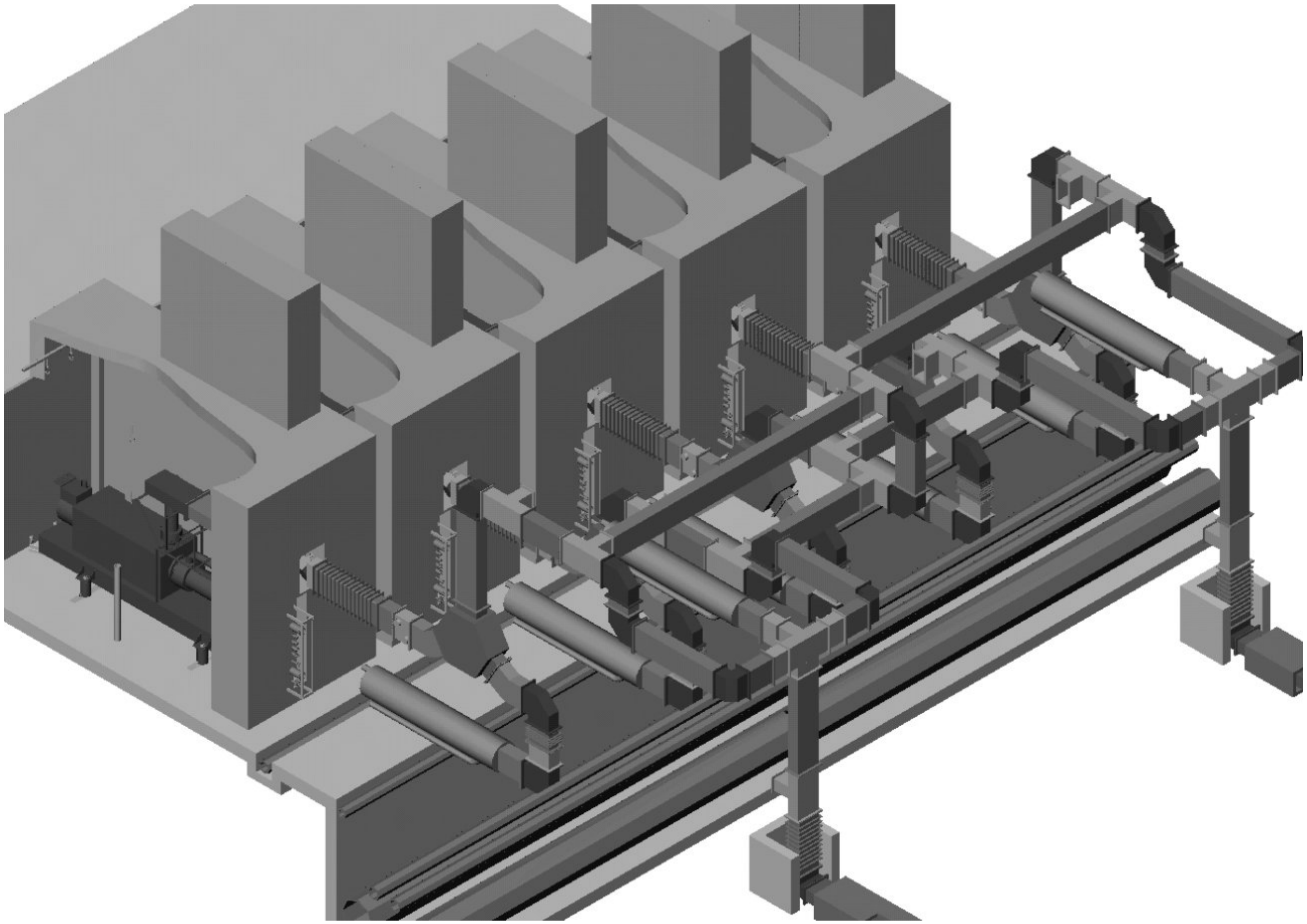
100 mA NC ADTF RF Arrangement

* 100 mA capability
* Center spare RF Station can replace any of other four.
* Replacement time = 800 ms.
* Two rf vacuum windows rather than four may suffice.

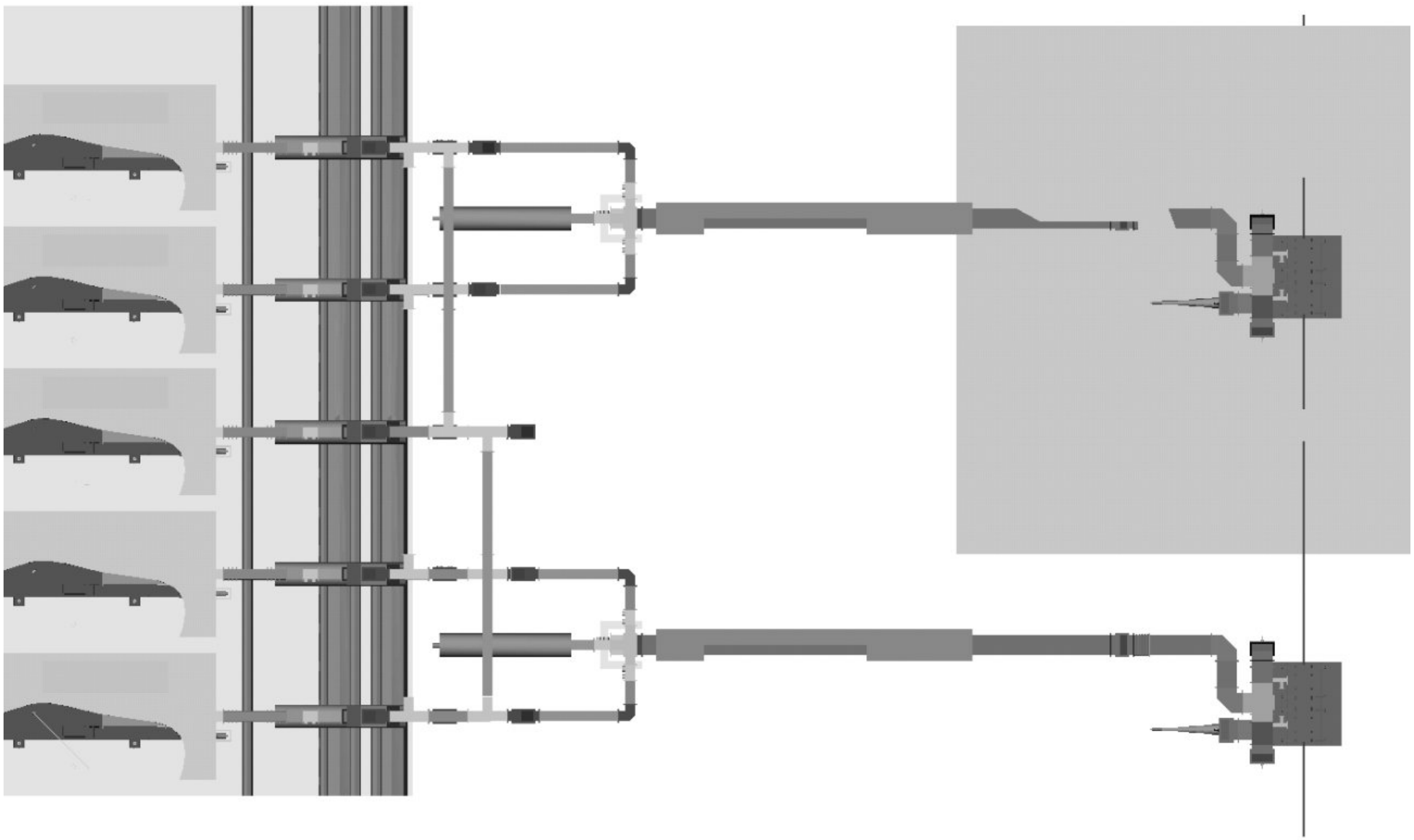
....

* More components in tunnel.
* Larger parts count
* No 300 ms ride-through capability.

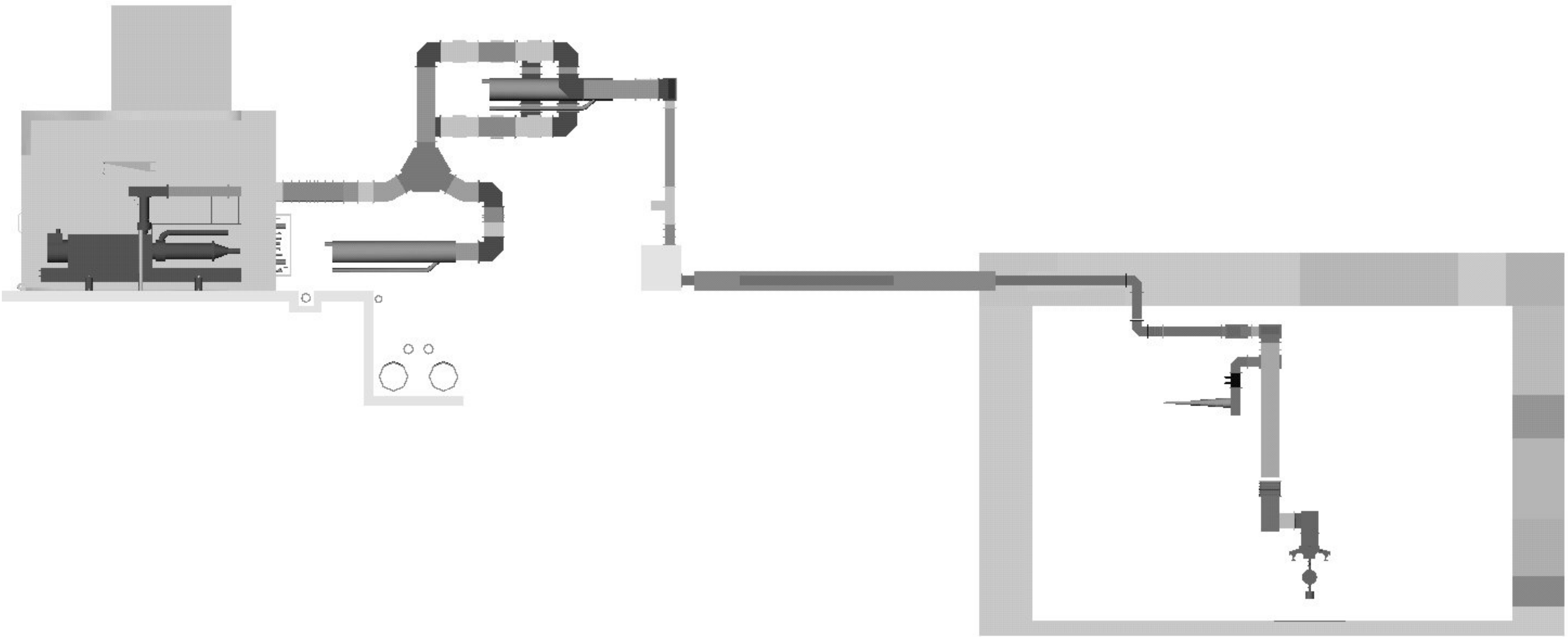
RF NC 100 mA Configuration



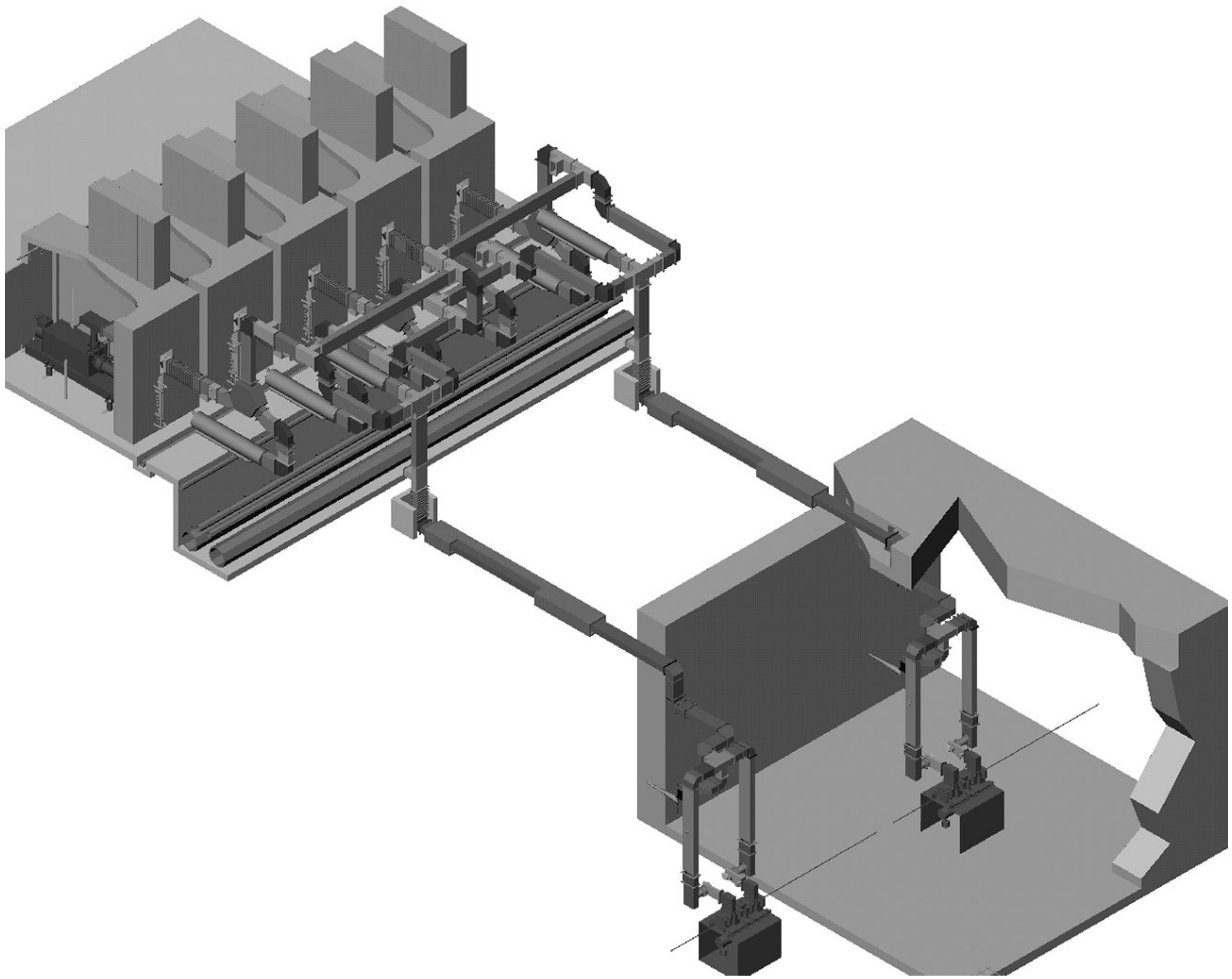
Plan View: RF NC 100 mA Configuration



RF NC 100 mA Configuration



100 mA RF NC Configuration



AAA

Operational Notes:

* The RFQ will continue to have nearly full incident RF power during a beam-off condition and should stay on resonance (approximately 1.33 MW to maintain field, 89.1 kW to accelerate 13.3 mA beam to 6.7 MeV).

* The CCL will stay within the cavity bandwidth during a short RF interruption. No need to go to frequency agile mode of LLRF control system.

* The CCDTL will require several cavity thermal time constants to come back to resonance after an 800 ms RF interruption.

ADTF RF Power ED&D Needs

* Waveguide Switches are required to isolate an rf station while the beam is in operation. LEDA WG switches have shown to be troublesome (arcs at the finger contacts caused by failed or misaligned limit switches). A development effort must be carried out to analyze the failures and produce a better switch.

* RF vacuum windows will take the beam down until repaired. New water-cooled planar windows (LBL-SLAC) have shown promise (hardly any arcing and a low thermal gradient at 800 kW). Continued testing of rf vacuum windows is necessary.

* RF vacuum valves that allow a failed window to be isolated in the SC linac have been studied and should be developed and tested.

* Fast ferrite phase shifters should be tested for high power and reliability. These could be very useful in eliminating waveguide components in the tunnel.

ADTF LE Linac RF Power Option Summary

AAA

Normal Conducting Linac Configuration	>300 ms faults < 100 seconds	# Faults over 100 sec.	Relative Percent Availability	Relative RF System Cost @ $3.00/Watt (Installed).	Normalized Cost	Notes
13.3 mA ADTF (Option 1) One 1 MW klystron per module (average delivered power = 720 kW)	0.0	72.4	97.47%	$87,000,000	0.66	Least Expensiv
13.3 mA ADTF (Option 2) One 1MW klystron per module plus spare klystron per two modules (720 kW delivered).	91.2	29.3	98.76%	$132,000,000	1.00	Better Availabili
13.3 (up to 32) mA ADTF (Option 3) Two 1MW klystrons per module, each is a spare for the other. Average delivered power = 360 kW	120.2	27.9	98.90%	$174,000,000	1.32	300 ms Ride-Through Capability, Best Availability
100 Ma ADTF (Option 4) Two 1MW klystrons per module with one spare per two modules. 720 kW delivered, 29 Modules	120.2	57.0	98.05%	$219,000,000	1.66	100 mA Configuration

AAA

Summary: Implementation Plan

* Fill garages at one klystron per module, begin early commissioning.

* Add spare klystrons as available, affording flexibility in spending rate.

* Add two klystrons per module to achieve 300 ms ride-through capability if required by target-multiplier.

* Add fifth klystron to NC garage set for 100 mA capability, if required.

* Replace 83 kW IOTs in SC linac with 500 kW klystrons (or replace 250 kW klystrons with 1MW units) to achieve 100 mA capability, if required.

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

Alternative Superconducting Low Energy Linac Design --- Linac Architecture

Tom Wangler

Why consider a superconducting low-velocity linac option?

- ¥ The new accelerator design goal for AAA is to reduce beam interrupts substantially to limit thermal stresses in the target.
- ¥ A superconducting linac provides advantages for reducing beam interrupts:

  -Combining a small number of cells per cavity (large velocity acceptance) with independent phasing of the cavities and larger bore radius provides ability to continue beam delivery even with rf module or focusing magnet failures.

  -Superconducting linac allows beam continuity in presence of common faults. Can continue running with single point failures of RF modules, cavities, rf windows, magnets, magnet power supplies.

- A superconducting linac also provides other significant benefits from reduced power losses and larger apertures.
- It is important to ask whether a low-velocity superconducting linac is a better choice for ADTF.

Accelerating structures have now been demonstrated for acceleration of low-velocity beams.

AAA

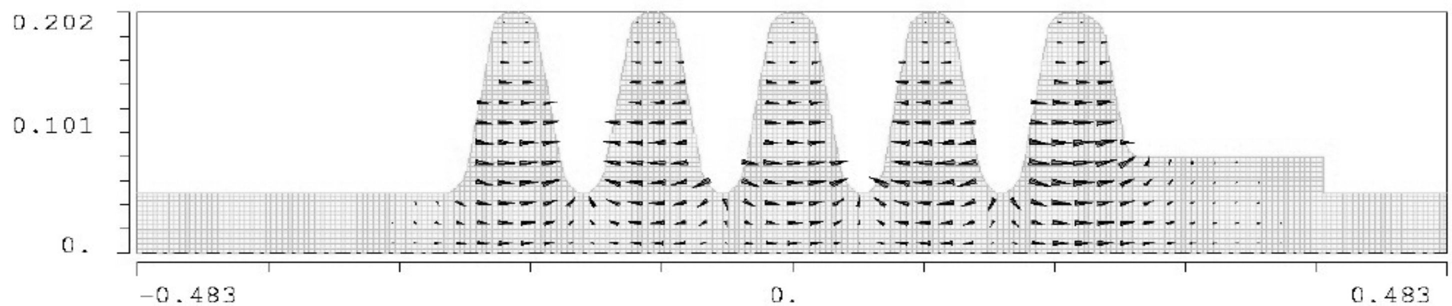
- LANL and Saclay/Milano have built and tested single-cell elliptical cavities near β=0.48. High gradients (>10MV/m) at 2K were achieved.

¥ The spoke cavity has been developed at Argonne as part of the RIA concept suitable for the lower velocity range from about β=0.2 to 0.5.

- High gradients (>10MV/m) were achieved last week at LANL in test of β=0.3 ANL spoke cavity at 4K.

¥ Using these accelerating structures it is now feasible to extend the superconducting linac all the way from 211 MeV to the end of the RFQ (6.7 MeV).

β=0.48 elliptical cavity electric field

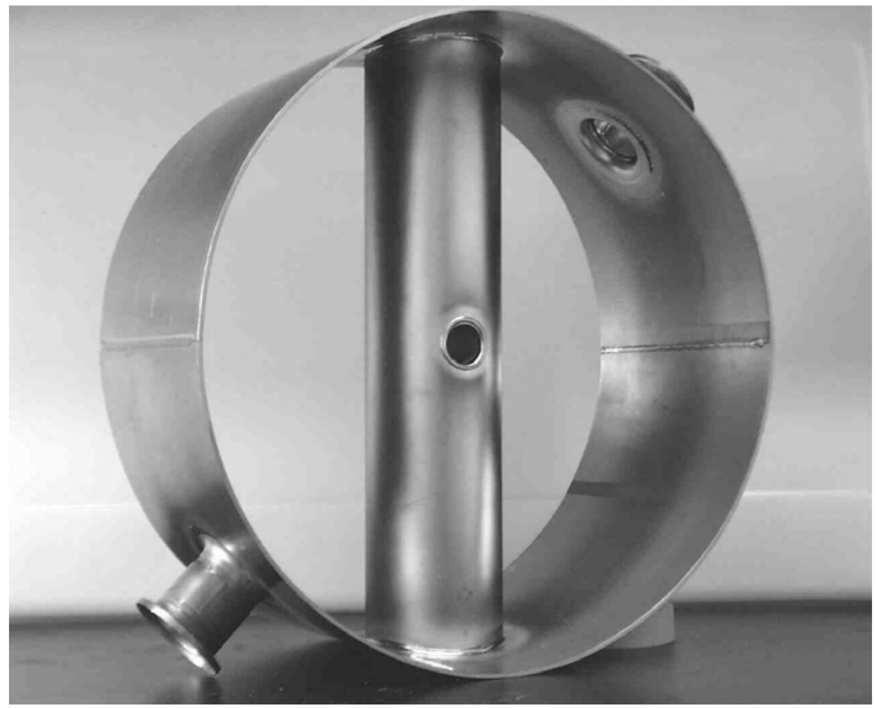


AAA

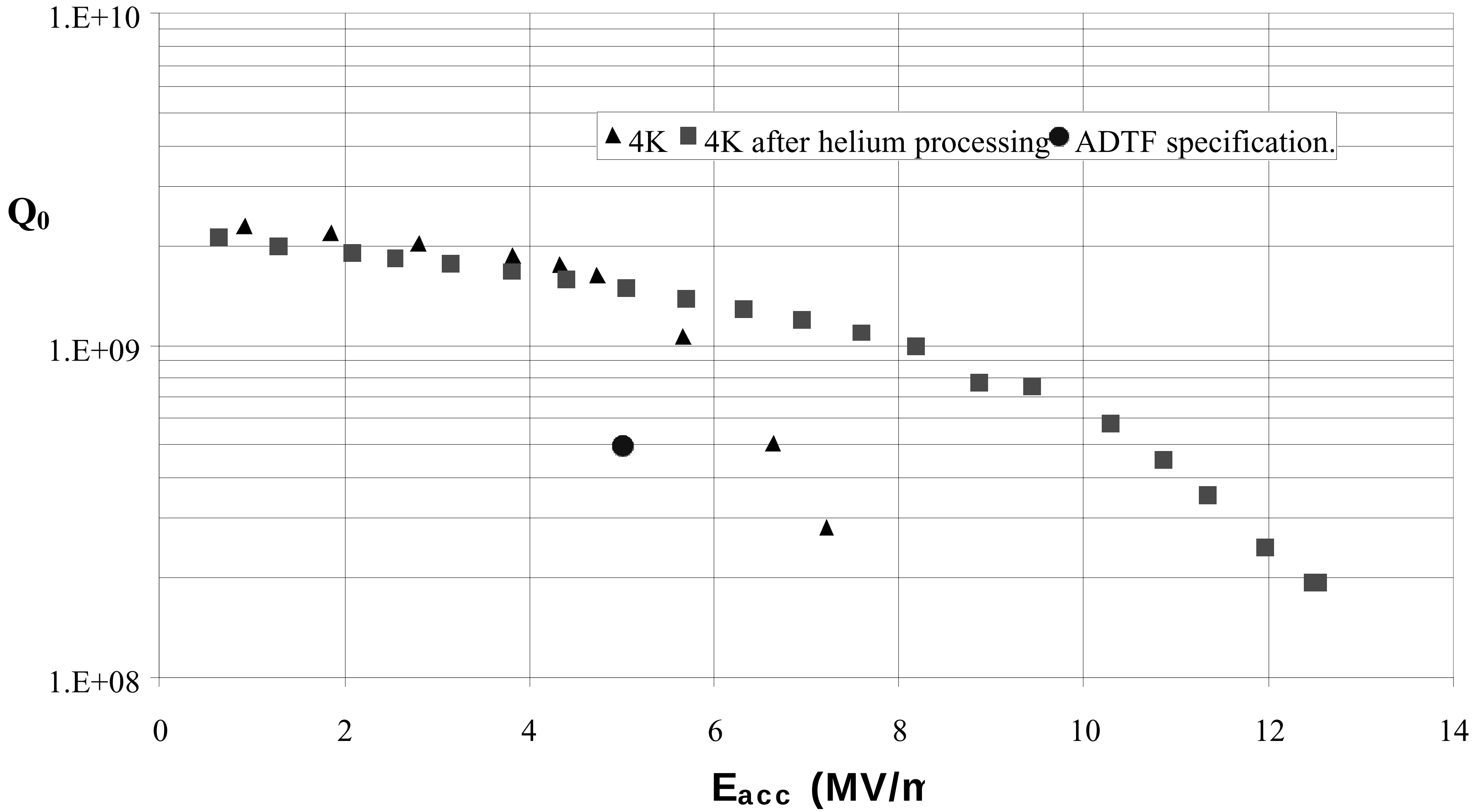
Spoke cavities for low-velocity applications have achieved high-gradient performance.

¥ 350-MHz 2-gap spoke structures for beta=0.3 and 0.4 have been developed by ANL for the proposed RIA project.

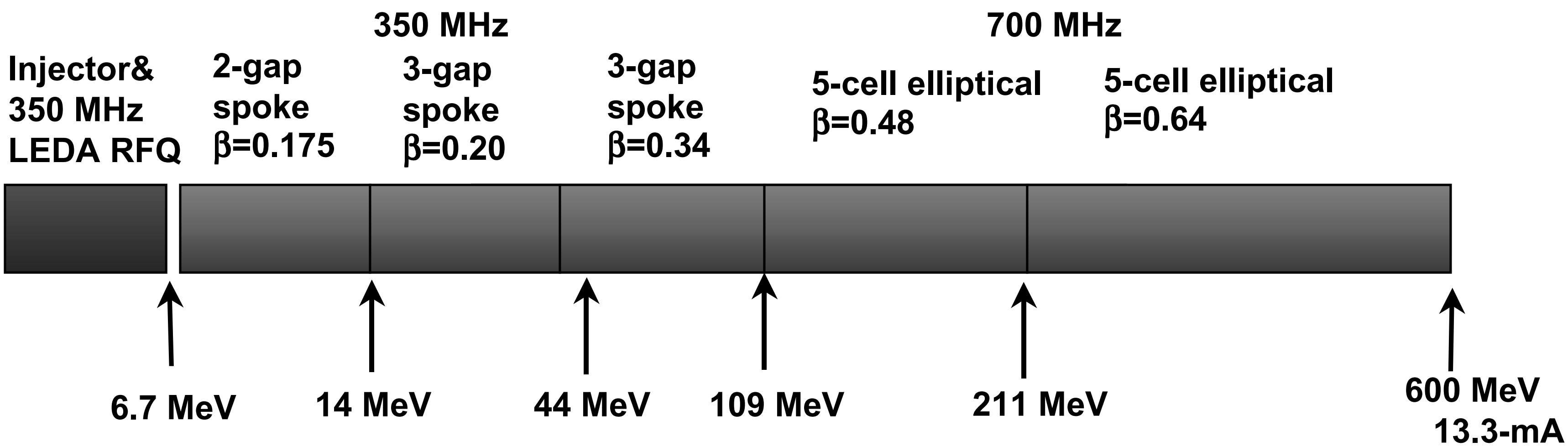
¥ Last week s tests of this cavity at LANL showed excellent high-gradient performance.



LANL measurements of ANL β=0.3 spoke cav
3/29-4/4, 2001

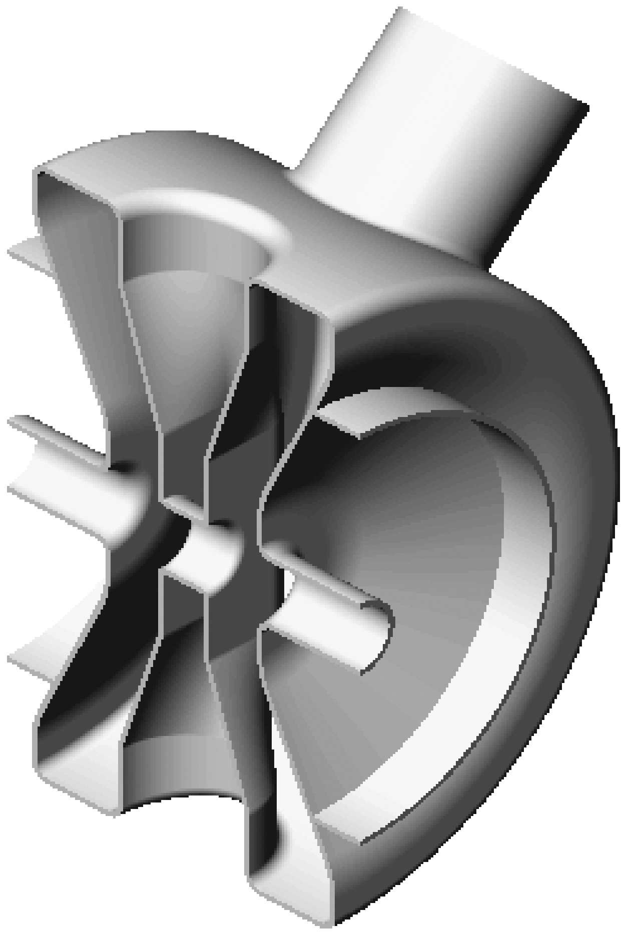


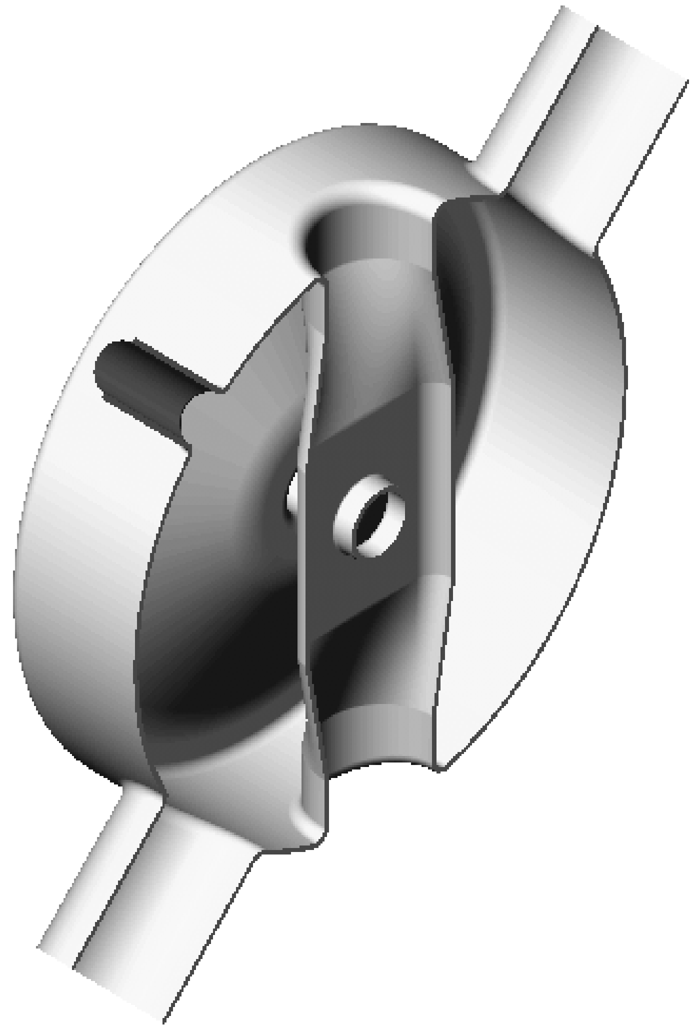
ADTF Superconducting Linac Present Design



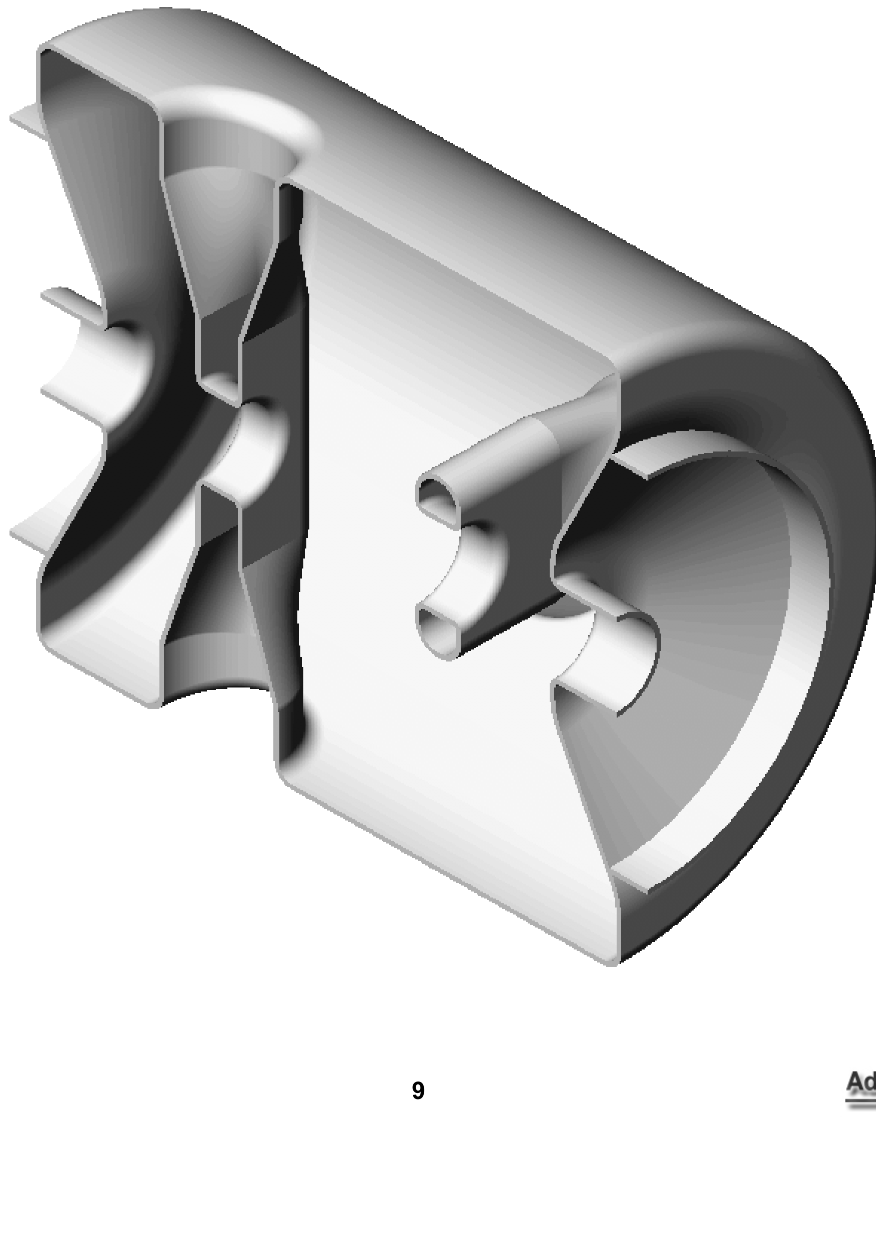
¥ NC linac to 211 MeV replaced with four new SC sections each with identical cavity shapes and cryomodules.
¥Conservative input power-coupler capacity < 60 kW and accelerating gradients (<10 MV/m).
¥Superconducting solenoid magnets used for focusing below 211 MeV.
¥New SC low energy linac saves 57 MW ac power.

β = 0.175 2-Gap Spoke Resonator Geometry

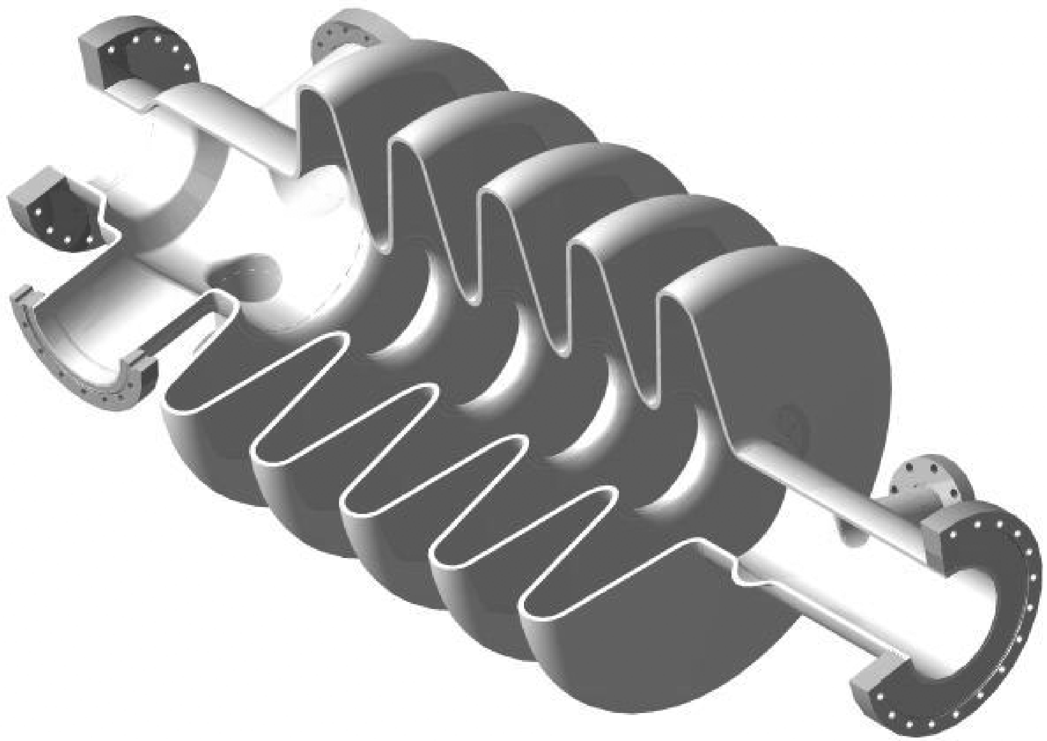




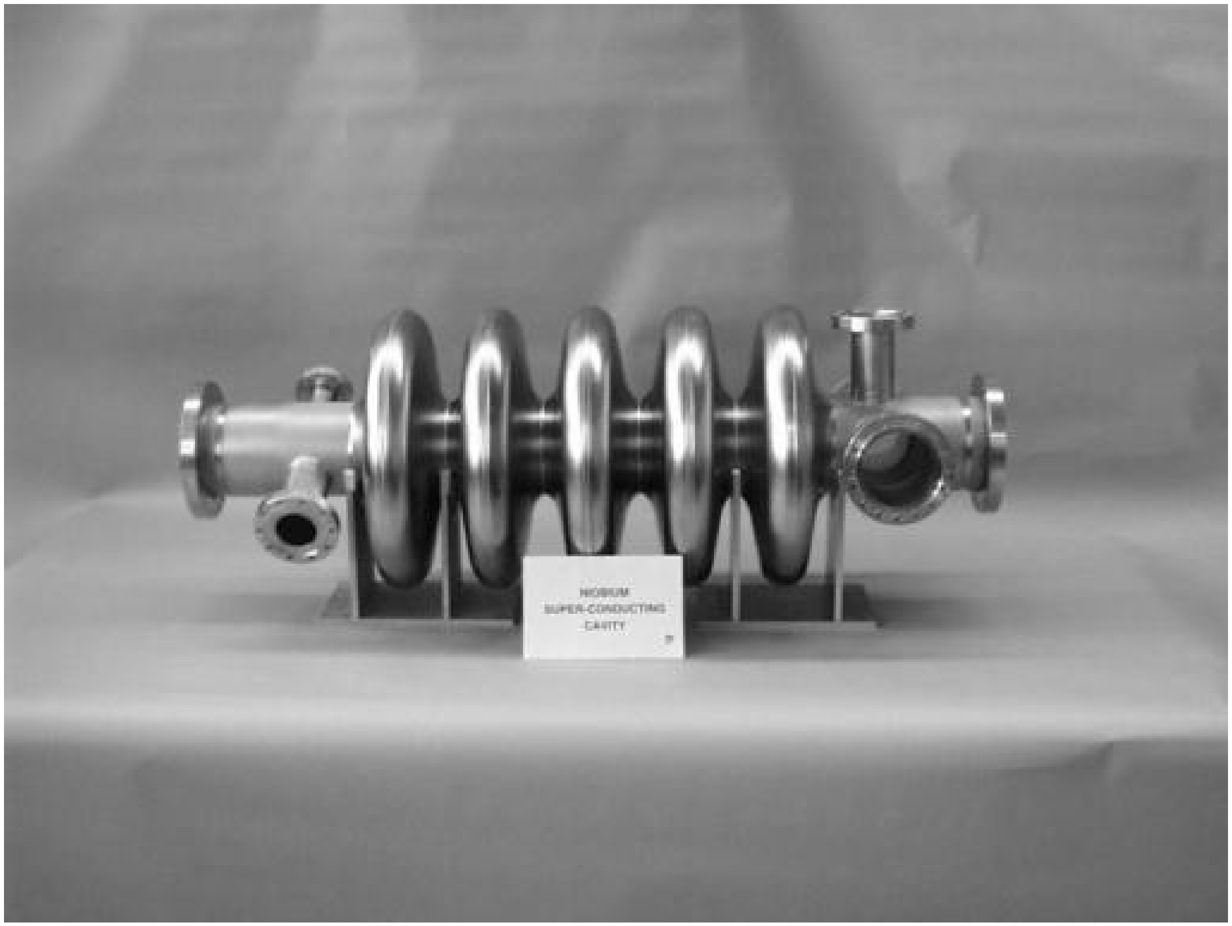
β = 0.34 3-Gap Spoke Resonator Geometry



β=0.48 elliptical cavity



APT beta=0.64 cavity



AAA

ADTF Alternative Superconducting Linac Parameters

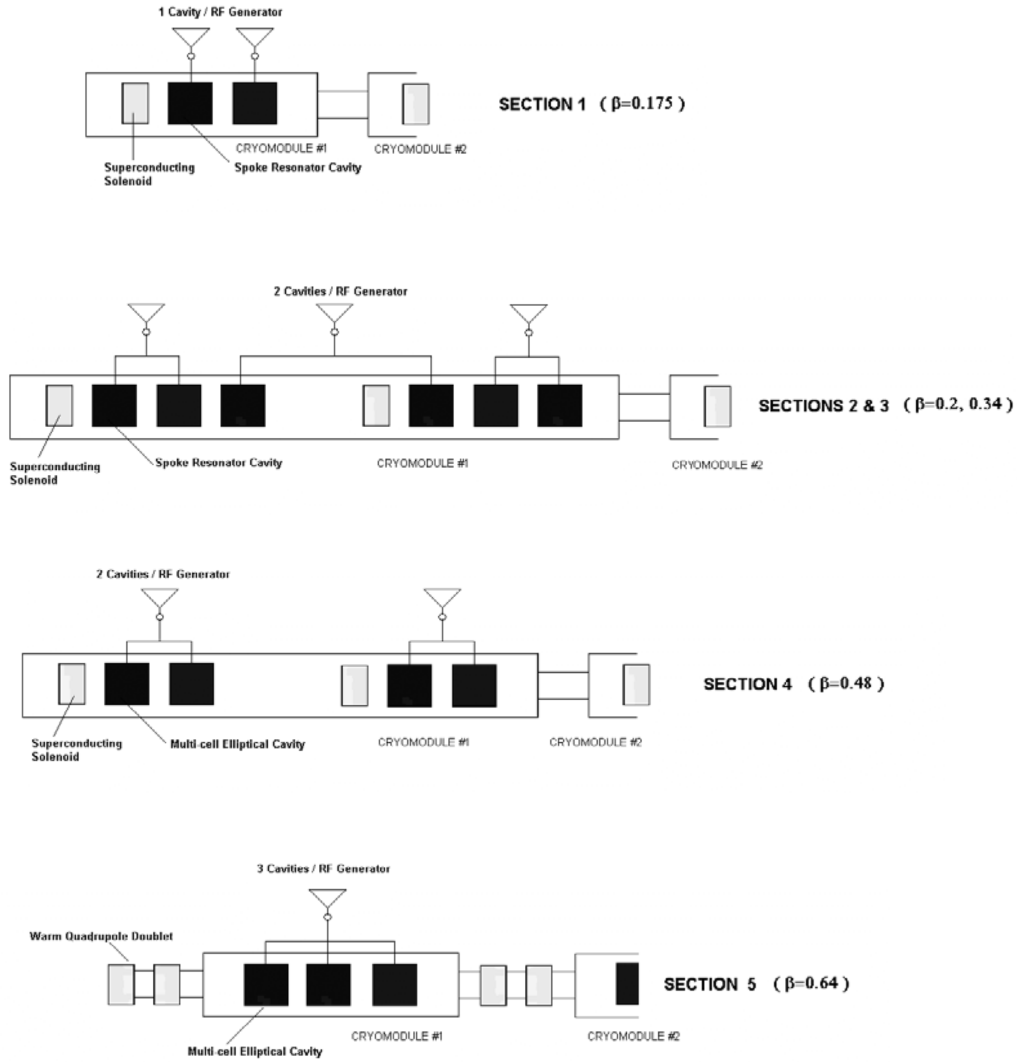
	Section 1	Section 2	Section 3	Section 4	Section 5	Total
Structure Type	2-gap spoke	3-gap spoke	3-gap spoke	5-cell ellipt	5-cell ellipt	
Frequency (MHz)	350	350	350	700	700	
Cavity Geometric Beta	0.175	0.2	0.34	0.48	0.64	
Cavity Bore Radius (cm)	2.0	3.5	4.0	5.0	6.5	
Cav/cryomodule	4	6	6	4	3	
Cav/section	32	48	48	40	93	261
No. of cryomodules	8	8	8	10	31	65
DW/cav (MeV)	0.08 - 0.35	0.33 - 0.78	0.86 - 1.40	0.95 - 2.73	4.22	
Win,section (MeV)	6.7	14.2	43.5	109.0	211.0	
Wout,section (MeV)	14.2	43.5	109.0	211.0	600.0	
Section Length (m)	36.2	48.8	55.4	64.8	191.6	396.8
Coupler Power @ 13.3 mA (kW)	4.7	10.4	18.6	36.3	56.1	
No. of Cavities per RF Generator	1	2	2	2	3	
No. of RF Generators	32	24	24	20	31	131
Magnet Type	SC Solenoid	SC Solenoid	SC Solenoid	SC Solenoid	RT Quad Doublet	

Superconducting low-energy linac design choices

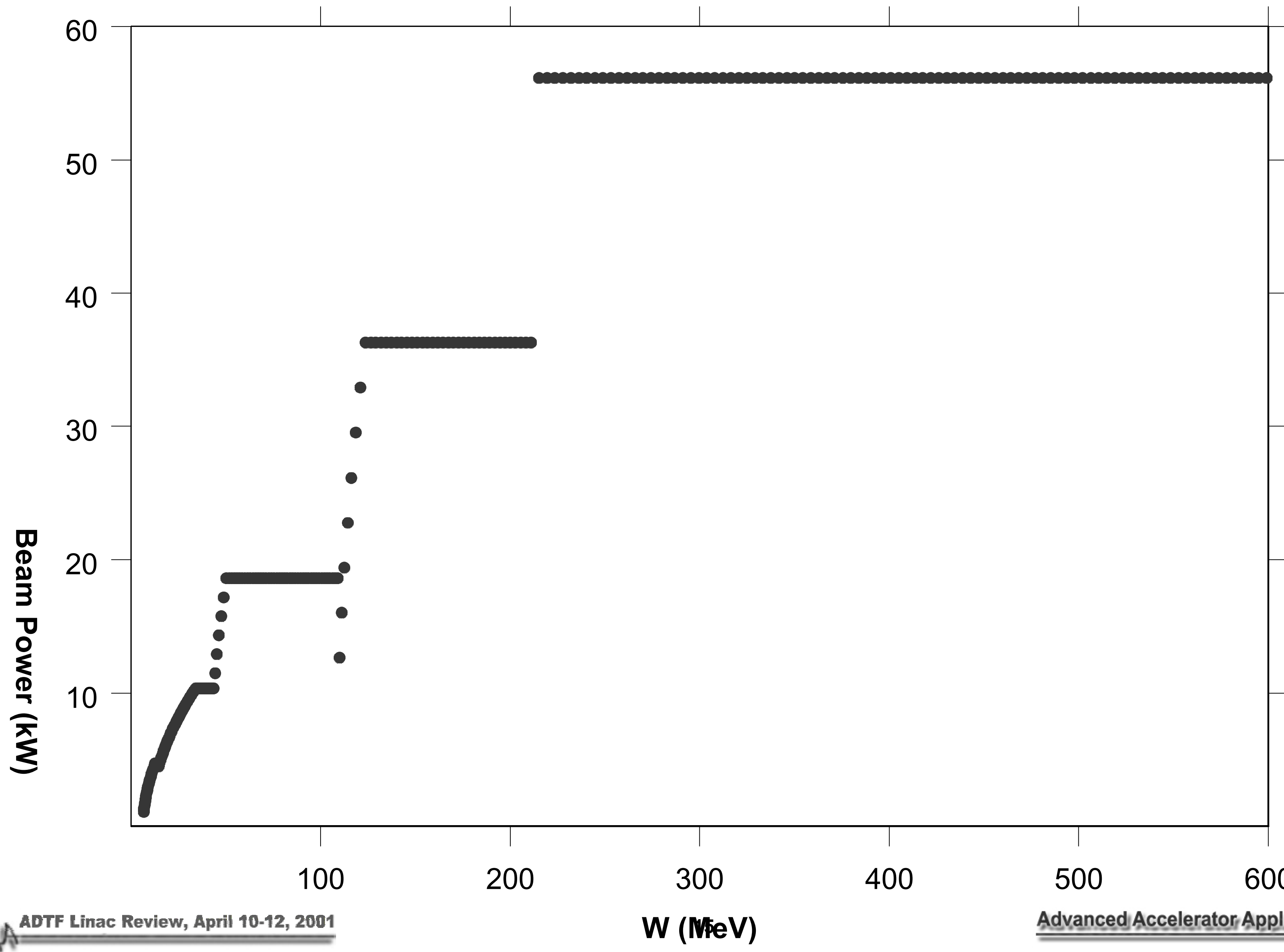
AAA

- ¥ Number of cells per cavity is chosen small enough to cover the velocity range with just a few cavity shapes.
- ¥ Conservatively chosen accelerating gradients allows margin for fault compensation.
  -E_{acc}< 10 MV/m for β=0.64 700-MHz elliptical cavities.
  -E_{acc}< 7 MV/m for β=0.48 700-MHz elliptical cavities.
  -E_{acc}< 5 MV/m for 350-MHz spoke cavities.
- ¥ RF generator sizes chosen sufficiently small to allow continued beam operation if an RF module fails.
- ¥ Design for large aperture to rms ratio especially for beam energies above 50 MeV where activation concerns are greatest.
- ¥ Use superconducting solenoids to provide compact focusing lattice to control emittance and halo growth from space-charge forces. (β=0.48 section could use quad doublets instead.)

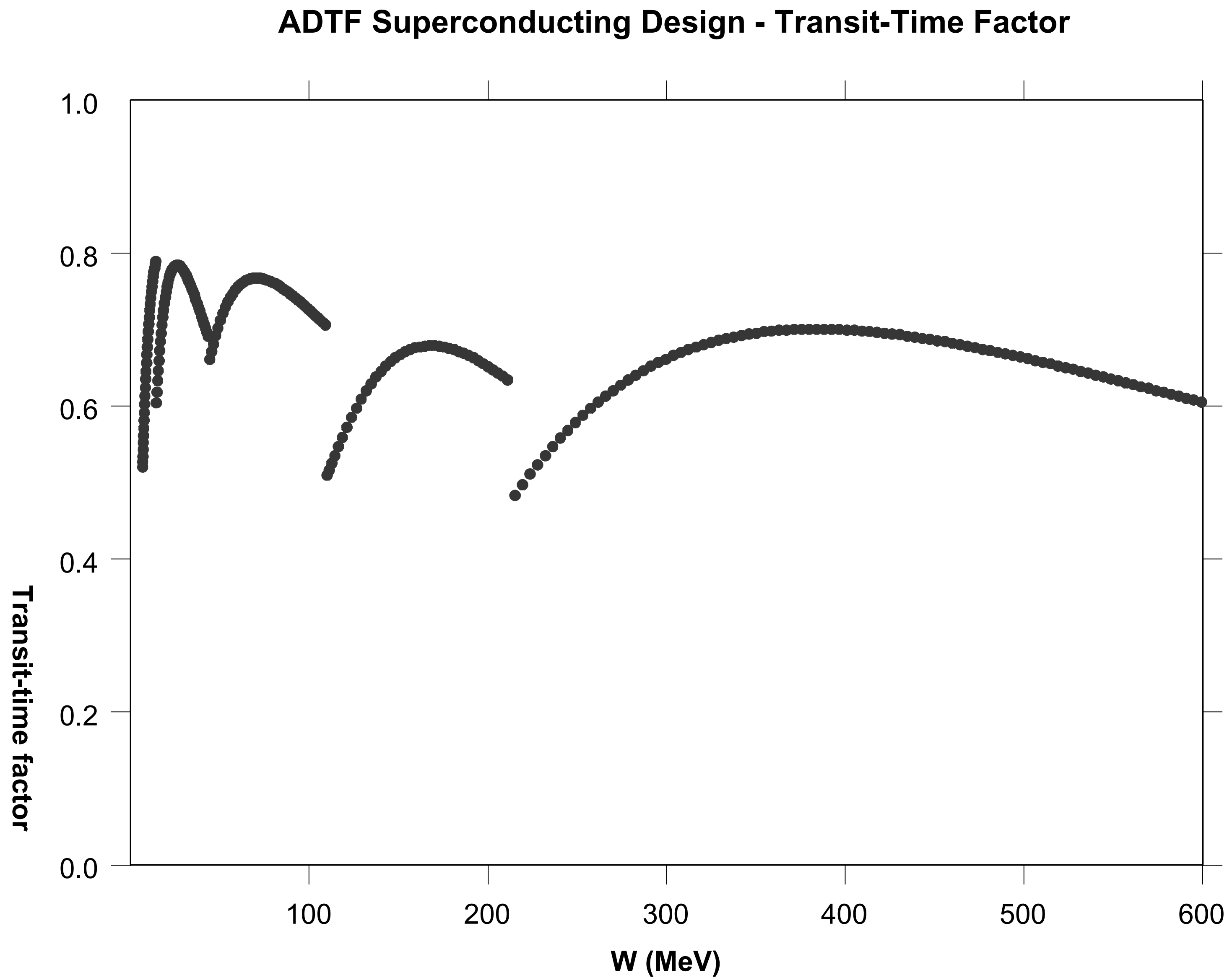
RF architectures for the 5 superconducting sections



ADTF Superconducting Design - Beam Power



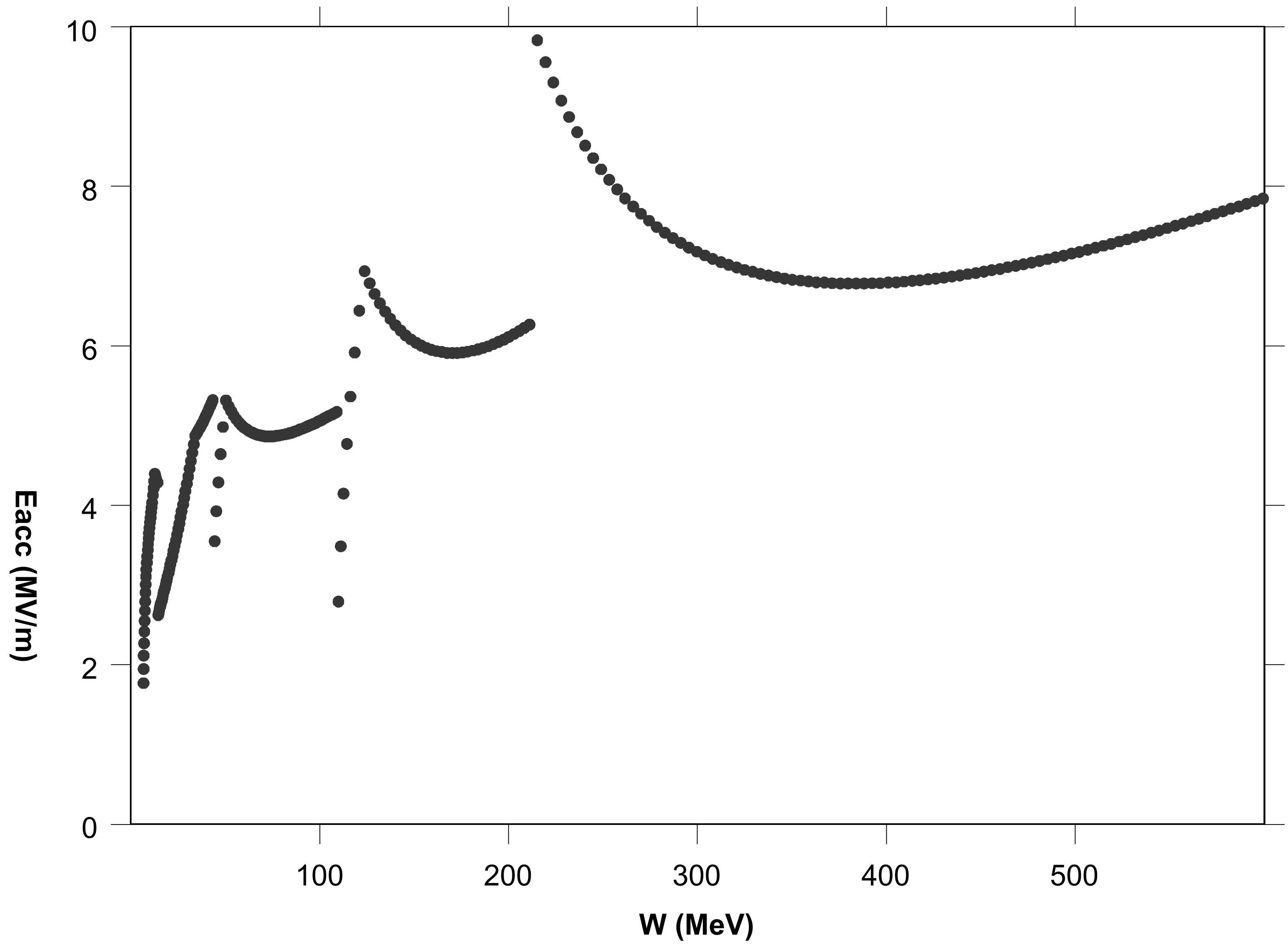
AAA



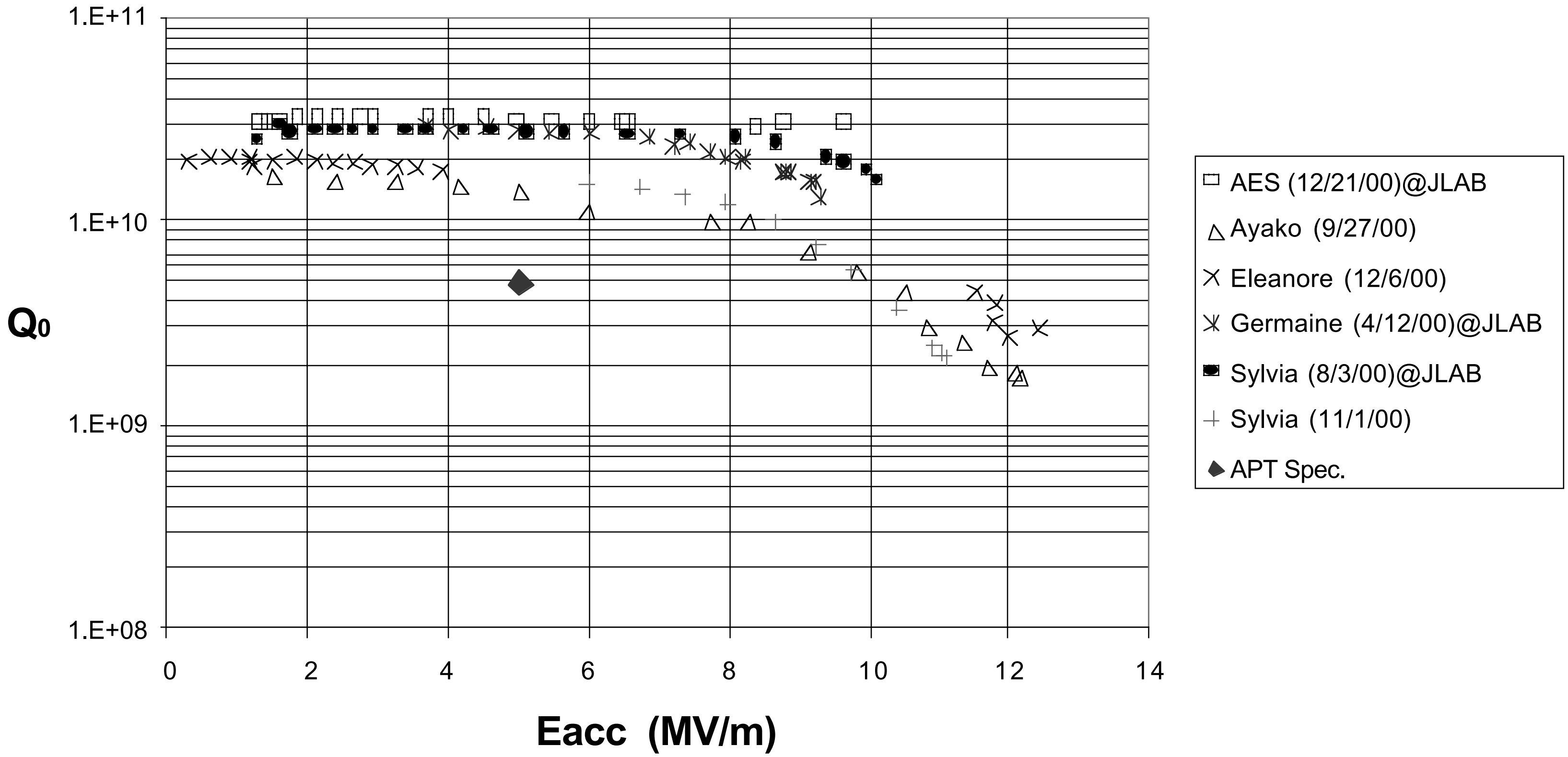
ADTF Linac Review, April 10-12, 2001

AAA

ADTF Superconducting Design - Accelerating Gradient $E_{acc}=E_0T_{max}$

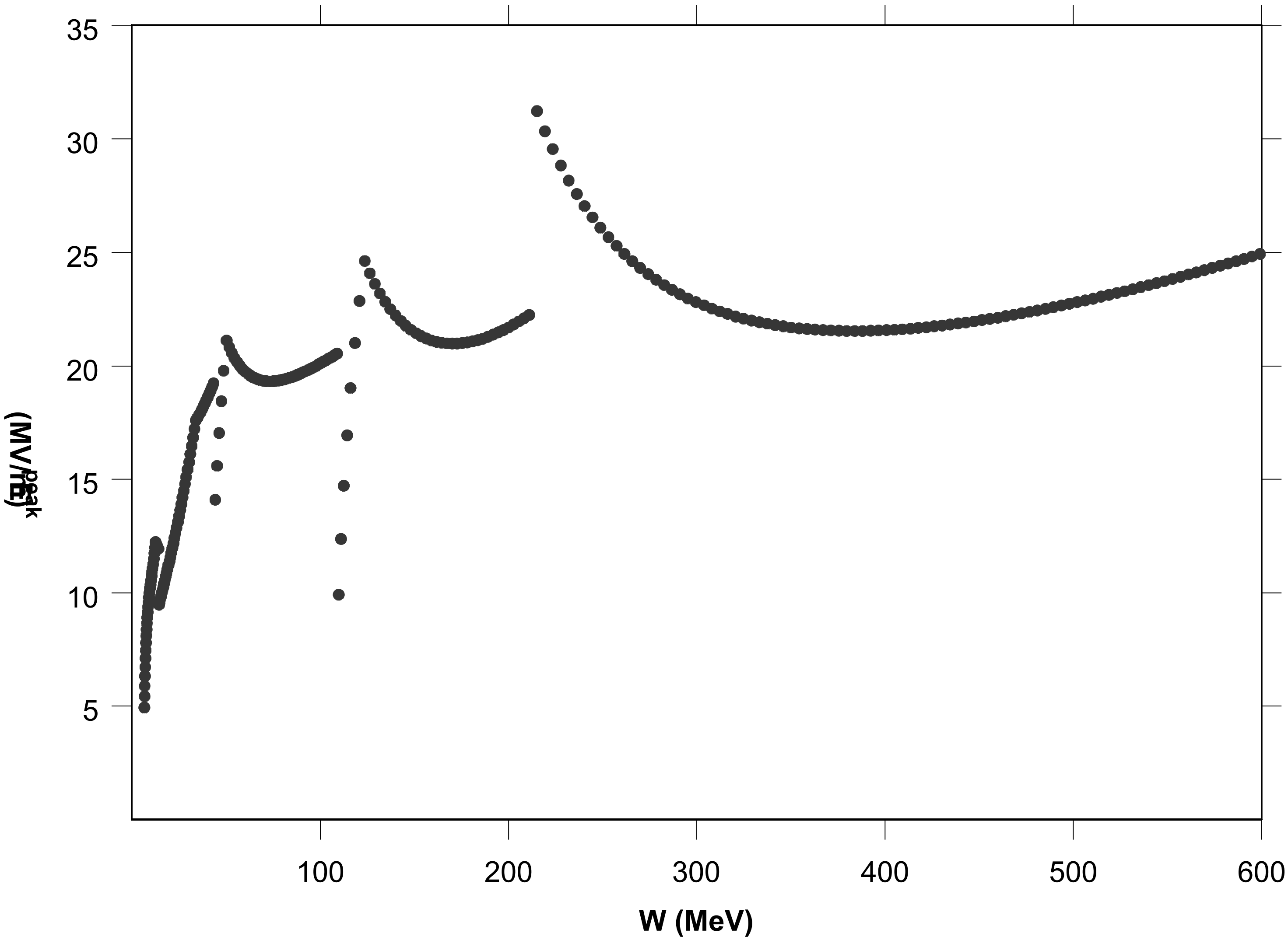


Results of Five APT 5-cell Cavities

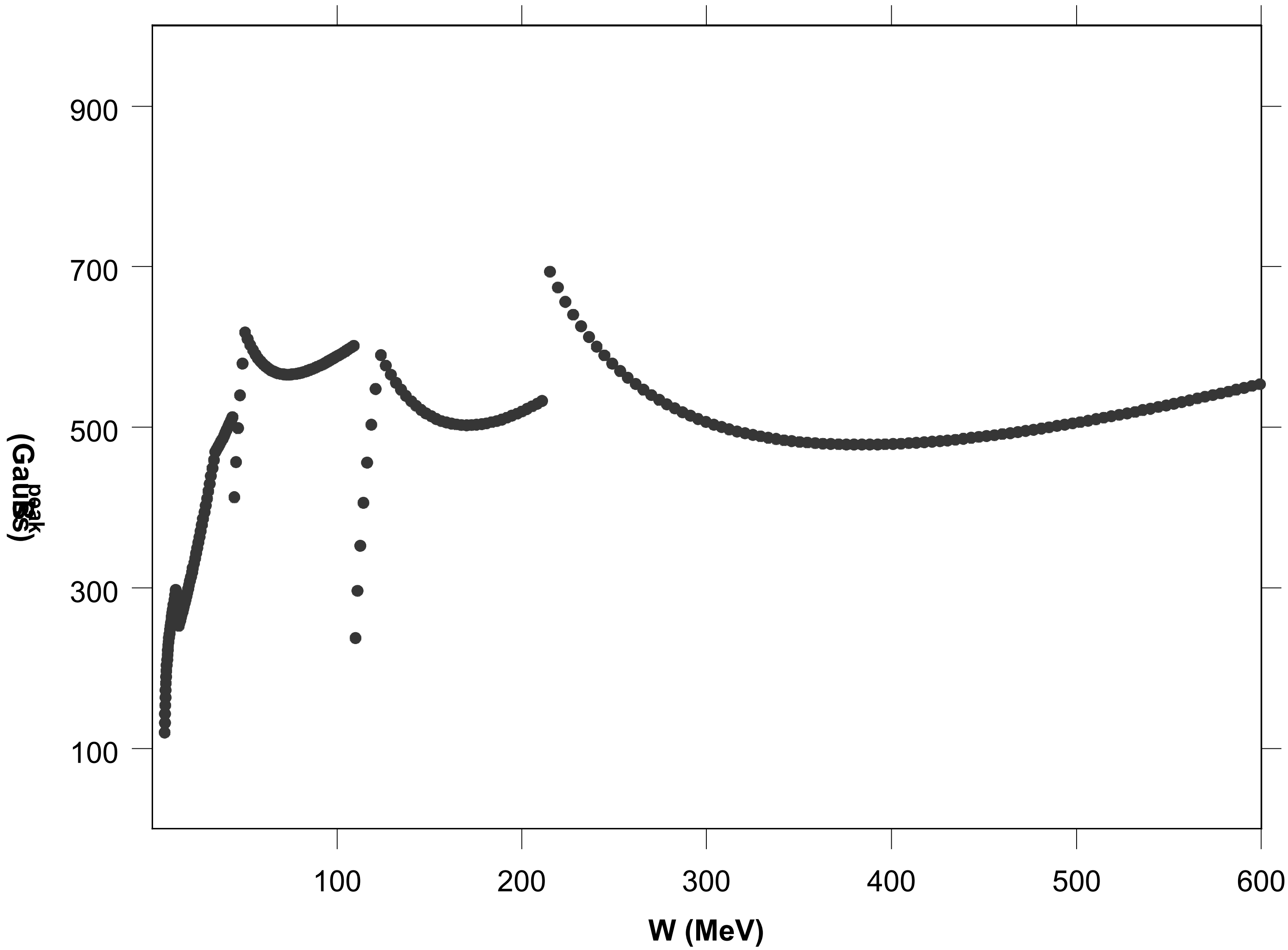


AAA

ADTF Superconducting Design - Peak Surface Electric Field



ADTF Superconducting Design - Peak Surface Magnetic Field



AAA

Superconducting linac can continue delivering beam even with component failures.

- Superconducting modules can be independently phased for efficient acceleration over a wide velocity range.
- If there are cavity or cryomodule failures, the downstream modules can be rephased to recapture the beam. Other cavity gradients can be increased to restore the 600-MeV final energy.
- Larger bore radius allows off energy or less well focused beams after faults to be transported to the target without significant beam losses.
- Repairs can be made during scheduled maintenance.

Simulation results for ideal linac show superconducting linac provides ways for reducing most common beam interrupts in the linac.

- Cavity failure anywhere in the linac.
- Detection of RF window performance degradation anywhere in the linac.
- RF generator system failure anywhere in the linac.
- Single focusing solenoid failure anywhere in the linac: No compensation required.
- Magnet power supply failure does not affect operating superconducting magnets because the superconducting magnets operate in a persistent current mode with no power supply connected.

194

AAA

Some additional advantages of a low-velocity ADTF superconducting linac

- Cavity RF power dissipation is reduced by almost 10^5 factor; AC operating power is substantially reduced.

  -Saves 57-MW AC power out of 80-MW total for 600-MeV linac.

- Larger bore radius becomes affordable, relaxing alignment, steering, and matching tolerances, and reducing beam loss and activation threat.

  -Aperture increases typically by factor of 2 in low-velocity linac.
  -Aperture to rms size ratio from 50 to 211 MeV increases by an average of about 40% .

TPO-RGN-1003

ADTF Linac Review, April 10-12, 2001

AAA

Summary

- A superconducting low-velocity linac provides more ways for reducing beam-interrupts in the linac.
- A superconducting low-velocity linac provides larger apertures, relaxing alignment, steering, and matching requirements, and reduces activation threat.
- A superconducting low-velocity linac provides significantly reduced operating power. Saves 57 MW out of 80 MW.
- The superconducting elliptical β=0.48 cavity and the superconducting spoke cavities provide the AAA program with an opportunity for an ADTF with a superconducting linac from 6.7 to 600 MeV.
- **If ADTF goals include addressing the beam-interrupt issue, the low-velocity superconducting linac should remain an option.**

AAA

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

Superconducting Low-Energy Linac Beam Dynamics

Robert Garnett

ADTF Linac Review, April 10-12, 2001

TPO-RGN-1003

AAA

Outline

- Selection of Design Parameters
- SC Linac Beam Simulation Results
- Comparison to Baseline APT Design
- Fault / Failure Study Results
- Summary

Selection of Design Parameters

AAA

- LEDA RFQ output beam characteristics assumed.
- Cryomodule mechanical layout specified by engineering.
- Design Goals:

  Avoid Beam Envelope Instabilities

  Achieve Beam Capture

  Current-Independent Focusing Lattice

  Efficient Acceleration

  $\Rightarrow$ Selection of accelerating gradients, synchronous phases, and quadrupole gradients

- Adiabatic accelerating gradient ramping is required at low beam velocities:

  High accelerating gradients $\Rightarrow$ Excessive longitudinal phase-advance leads to beam loss.

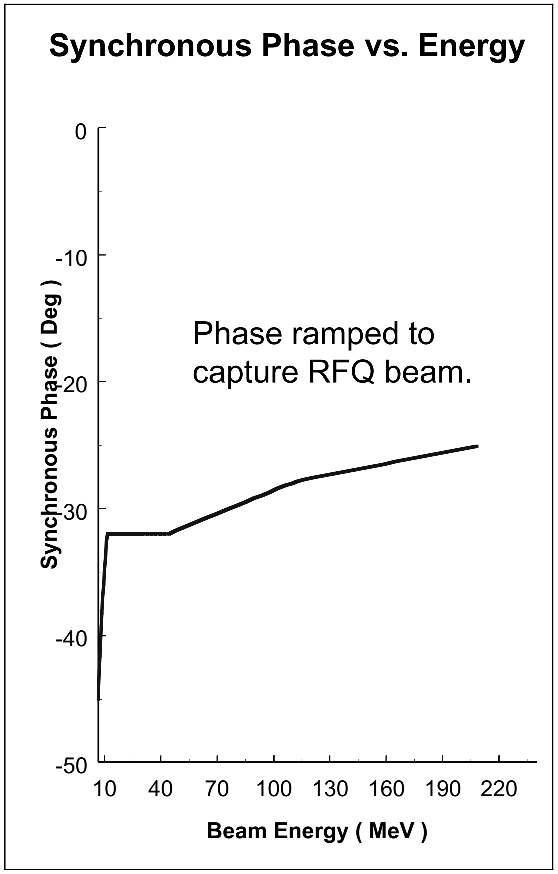
- Parameters are probably not yet optimized - several design cases examined.

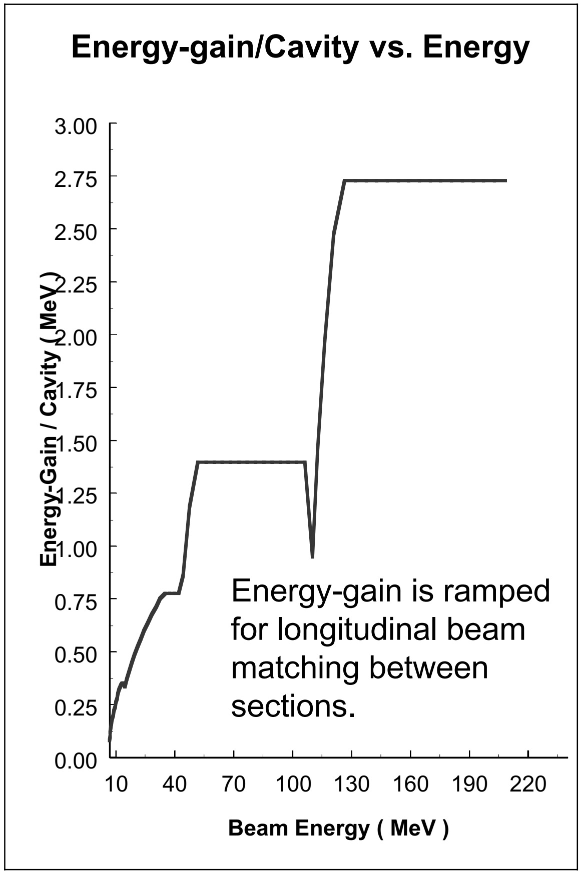
Superconducting ADTF Linac Parameters

	Section 1	Section 2	Section 3	Section 4	Section 5	Total
Structure Type	2-gap spoke	3-gap spoke	3-gap spoke	5-cell elliptical	5-cell elliptical	
Frequency (MHz)	350	350	350	700	700	
Cavity Geometric Beta	0.175	0.2	0.34	0.48	0.64	
Cavity Bore Radius (cm)	2.0	3.5	4.0	5.0	6.5	
L-cavity (active) (m)	0.100	0.196	0.333	0.514	0.685	
L-cavity (physical) (m)	0.200	0.296	0.433	0.900	1.200	
L-magnet-to-cavity (m)	0.300	0.300	0.300	0.300	0.000	
L-drift1 (m)	0.300	0.300	0.300	0.100	0.616	
L-drift2 (m)	1.113	1.113	1.113	1.088	0.616	
L-magnet (m)	0.150	0.150	0.150	0.250	0.350	
L-warm-to-cold-1 (m)	0.394	0.394	0.394	0.394	0.642	
L-warm-to-cold-2 (m)	0.419	0.419	0.419	0.394	0.642	
L-warm-space (m)	0.300	0.300	0.300	0.300	1.610	
L-cryomodule (m)	4.226	5.802	6.624	6.183	4.571	
L-cryoperiod (m)	4.526	6.102	6.924	6.483	6.181	
L-focusing period (m)	2.263	3.051	3.462	3.338	6.181	
Cav/cryomodule	4	6	6	4	3	
Cav/section	32	48	48	40	93	261
No. of cryomodules	8	8	8	10	31	65
DW/cav (MeV)	0.08 - 0.353	0.335 - 0.778	0.863 - 1.398	0.950 - 2.727	4.219	
Synchronous Phase (deg)	-45 to -32	-32	-32 to -28	-28 to -25	-25	
EoT (MV/m)	1.131 - 4.162	2.015 - 4.681	3.056 - 4.755	2.093 - 5.854	6.796	
Win,section (MeV)	6.7	14.174	43.544	109.043	211.015	
Wout,section (MeV)	14.174	43.544	109.043	211	600	
DW/section (MeV)	7.474	29.37	65.499	101.957	388.985	
Section Length (m)	36.208	48.816	55.392	64.83	191.596	396.842
Coupler Power @13.3 mA (kW)	4.7	10.35	18.6	36.27	56.11	
Coupler Power @100 mA (kW)	35.30	77.80	139.80	272.70	421.90	
No. of Cavities / RF Generator	1	2	2	2	3	
No. of RF Generators / Section	32	24	24	20	31	131
Magnet Type	SC Solenoid	SC Solenoid	SC Solenoid	SC Solenoid	RT Quad Doublet	
Magnet Field / Gradient	1.80 - 2.32 T	2.50 - 4.00 T	4.00 - 5.40 T	4.00 - 5.63 T	4.85 - 6.05 T/m	
Total Length Sections 1 - 4 (m)					205.246	
L-drift2 = L-w2c1 + L-w2c2 + L-warm						
L-cryoperiod = L-cryomodule + L-warm						

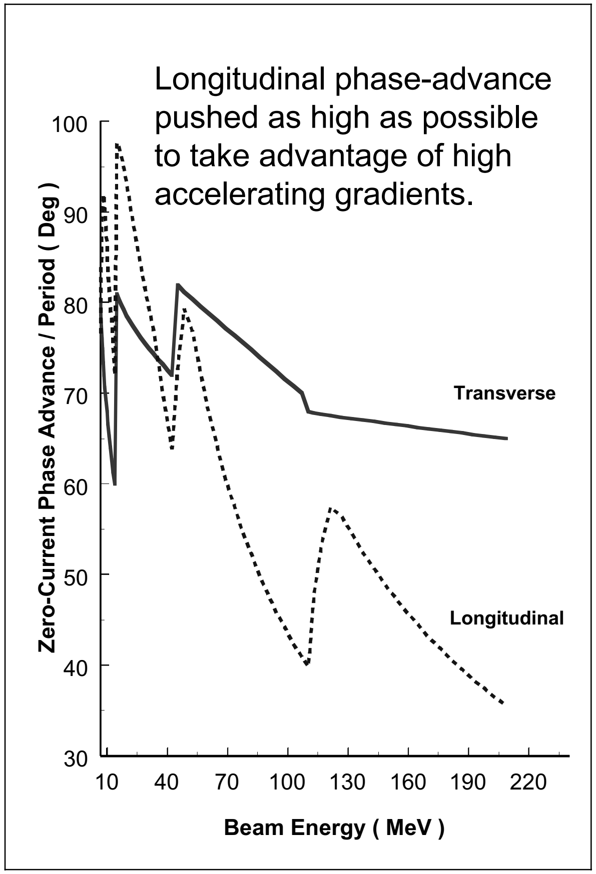
Synchronous Phase and Energy-Gain / Cavity

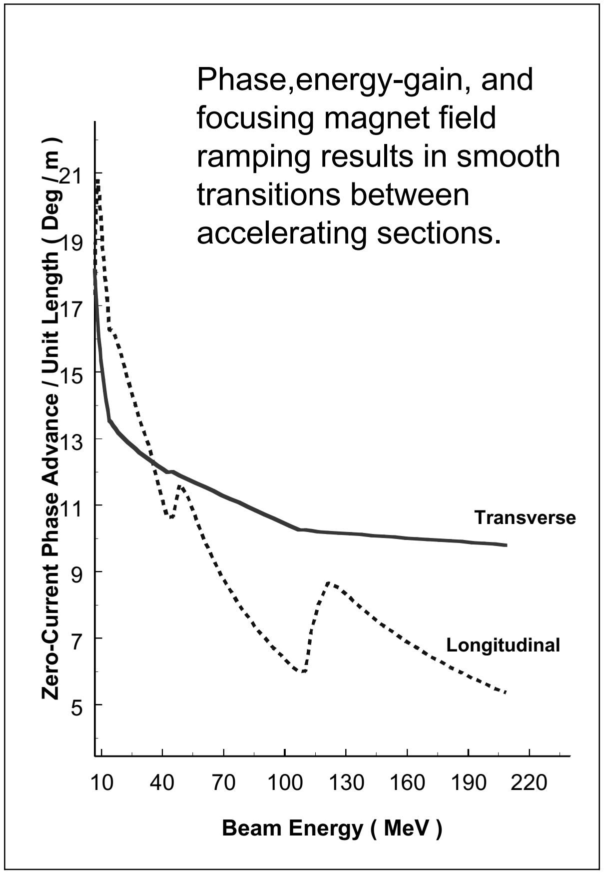
Superconducting ADTF Linac





Phase-Advance vs. Beam Energy





SC Linac Beam Simulations

AAA

- 10,000 macroparticle distributions from LEDA RFQ simulations used as input to the LINAC code:

  Beam currents - 0 mA, 13.3 mA, 100 mA

- Ideal linac simulated - no alignment or operational errors included yet.

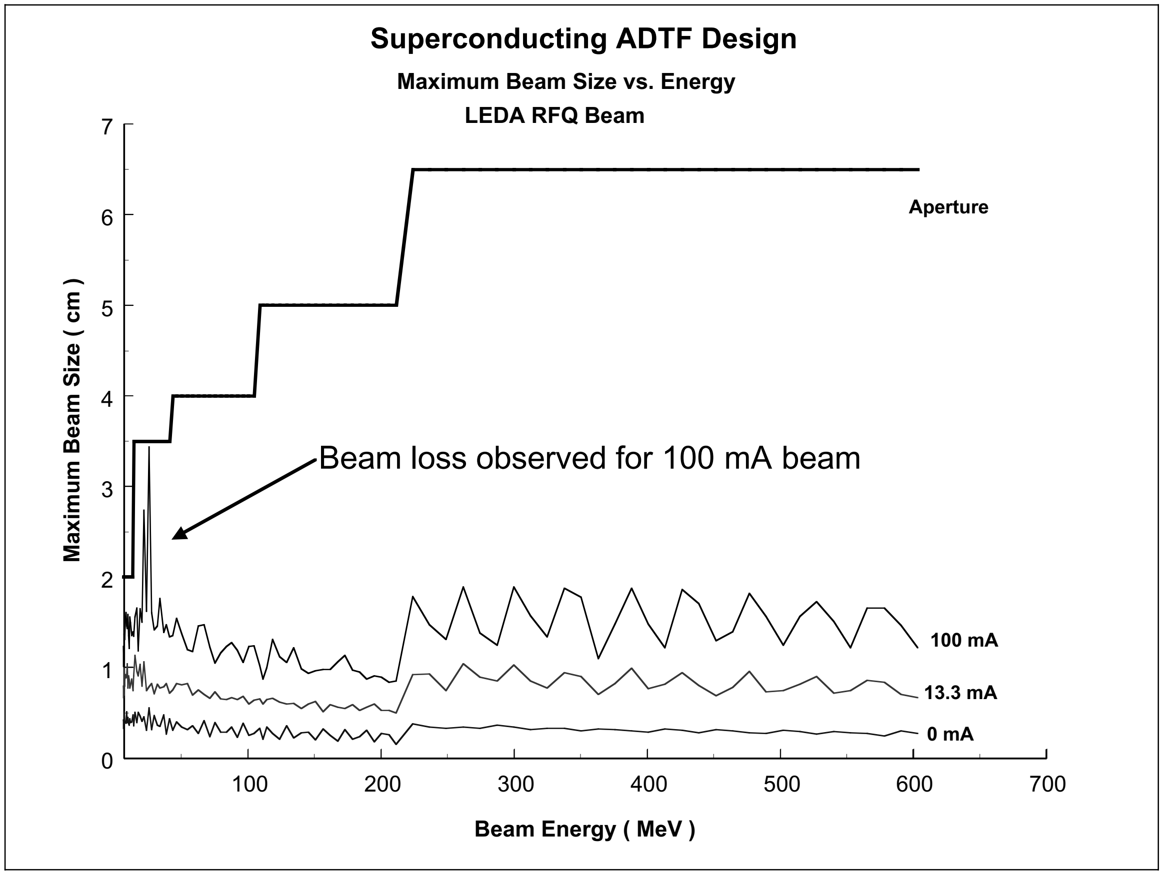
- Beam assumed matched at input to superconducting linac.

  RFQ beam transformed to rms matched beam parameters.

  Preliminary design of matching section not yet implemented.

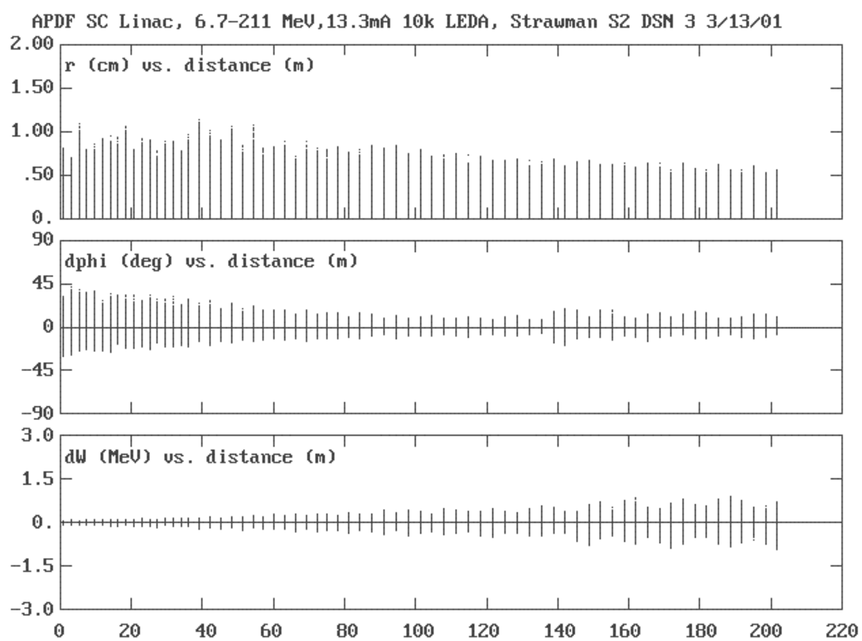
Beam Simulation Results

Ideal Linac, 10,000 Macroparticle LEDA RFQ Distribution

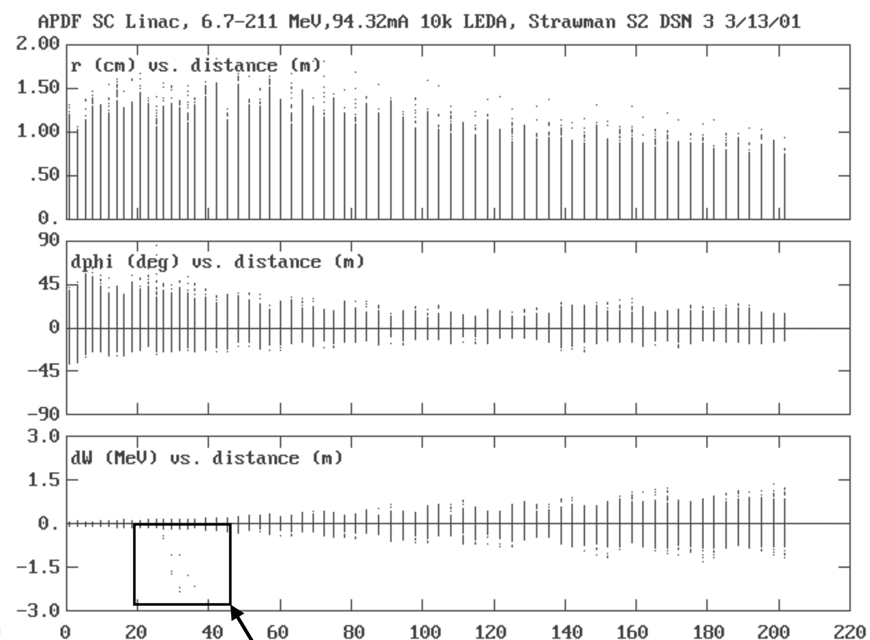


Small longitudinal beam loss at 100 mA can be corrected in next design iteration.

13.3 mA

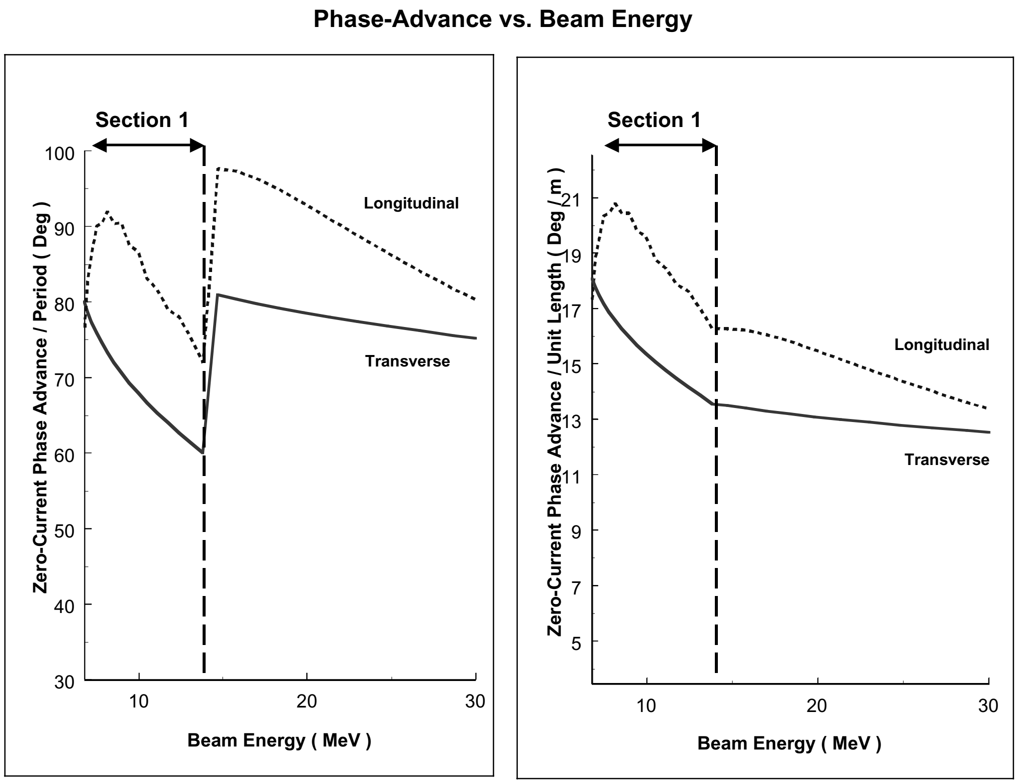


100 mA



Particles lost from the RF bucket

All 100 mA beam loss occurs in Section 1.



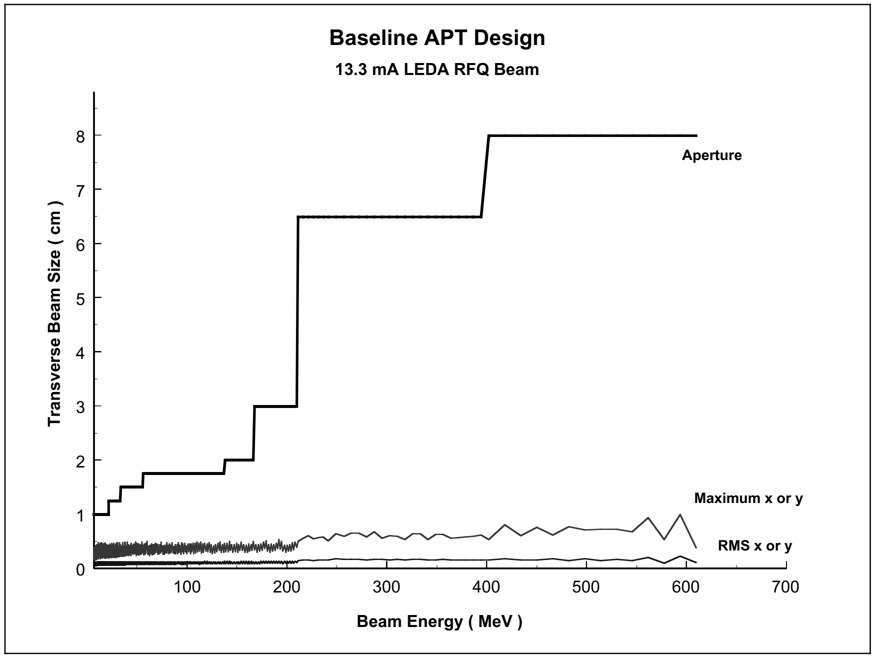
- ¥ 3 x 10^{-4} beam loss in Sec. 1
- ¥ Mean energy of lost particles = 11.1 MeV.
- ¥ Power Deposited = 330 Watts
- ¥ Large longitudinal phase-advance believed to cause losses.
- ¥ More adiabatic acceleration in Section 1 should eliminate losses.

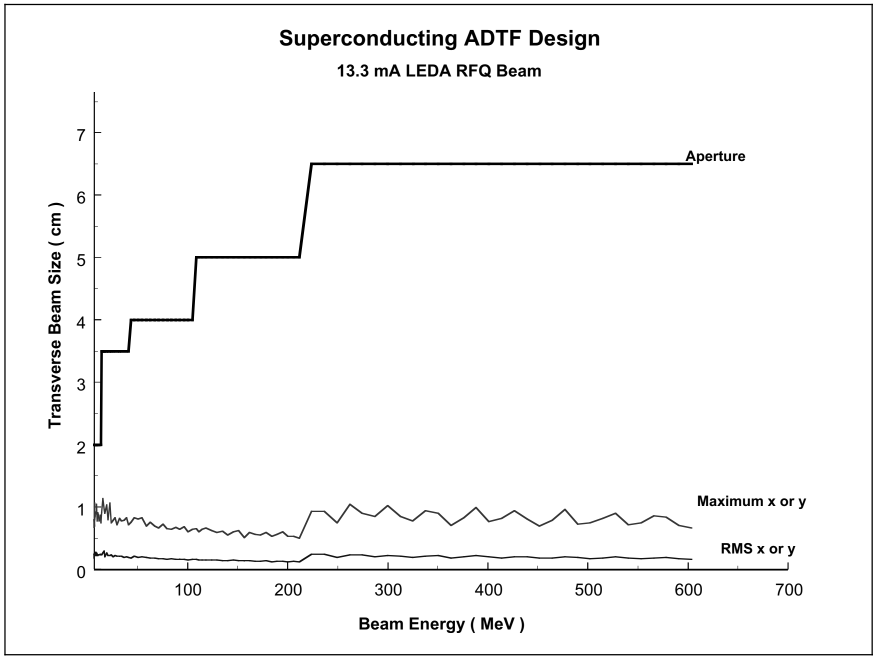
  ⇒ Lower gradient ramp rate

  Additional cavities required

Comparison to Baseline APT Design

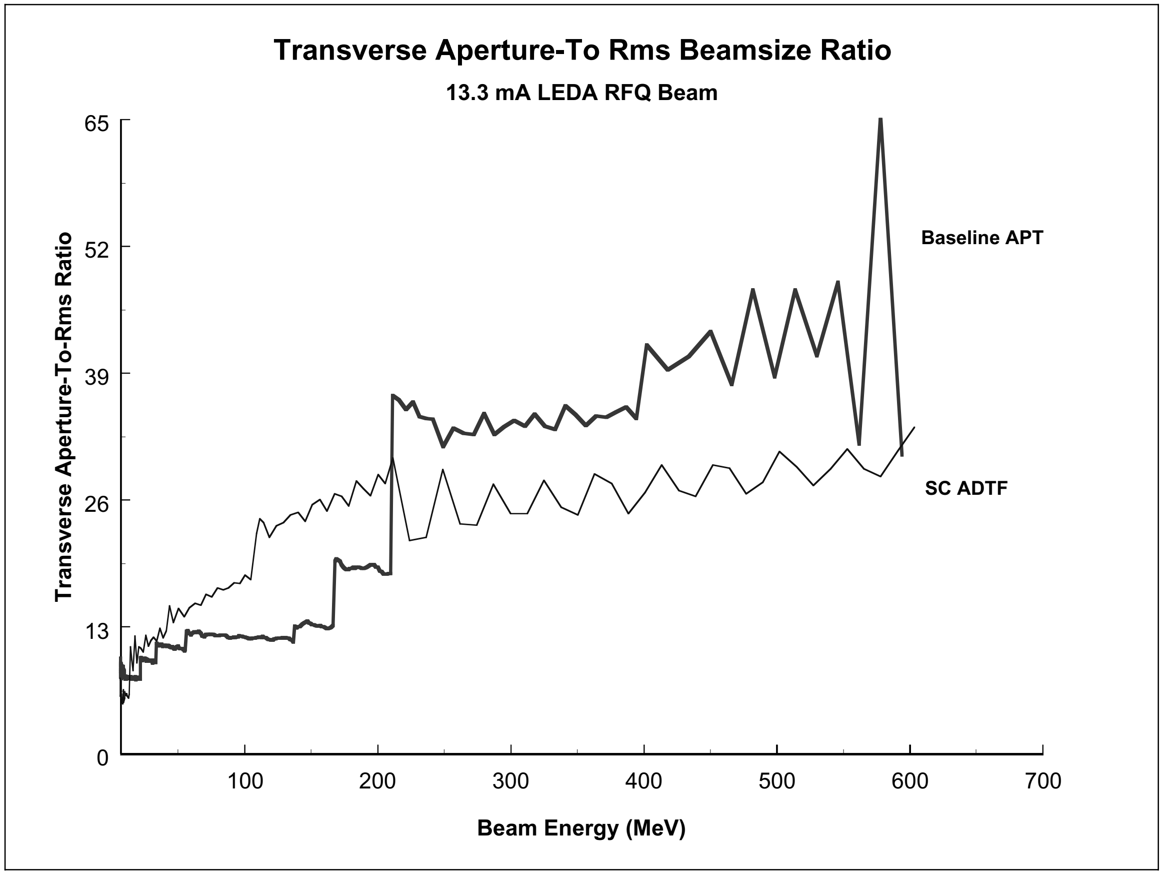
Transverse Beam Size - 13.3 mA





Comparison to Baseline APT Design - 13.3 mA (cont.)

Transverse Aperture-to-Rms Beam Size Ratio



Fault / Failure Study - 13.3 mA

¥ Studied effects of 2 types of component failures that can lead to long accelerator downtimes (> 100 sec):

1) Magnet Failures

2) RF System Failures -

Single-Cavity Failure (quench, RF window arcing, etc.)

RF Module Failure (klystron failed, multiple cavities off)

¥ Goal was to determine tolerances to these types of faults.

¥ Locations of failures for study -

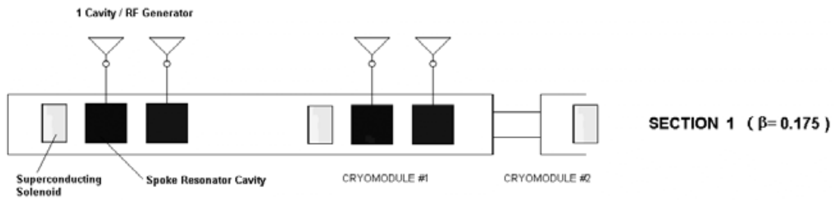
1st Solenoid of each section failed in Sections 1-4

1st Doublet failed in Section 5

1st RF Cavity or RF Module of each section failed in Sections 1-4

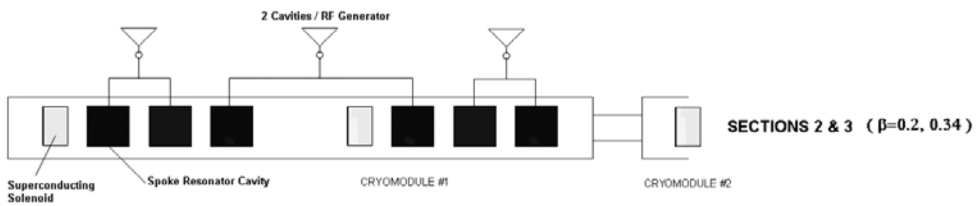
Fault / Failure Study (cont.)

RF System Architecture



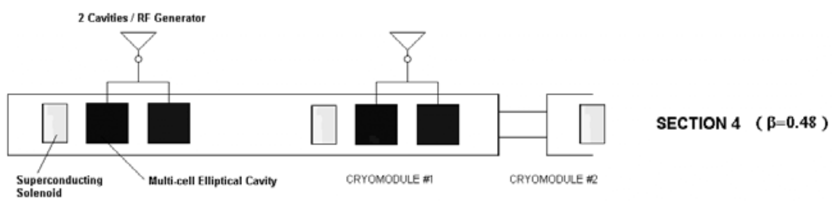
Section 1

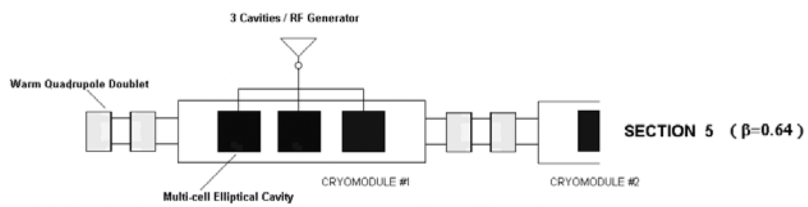
RF Module Failure = Cavity Failure



Section 2 - 4

RF Module Failure = 2-Cavity Failure





Section 5

RF Module Failure = 3-Cavity Failure

Identical to Baseline APT Design

Fault / Failure Study Results

- ¥ Single-magnet failures in ideal linac appear tolerable.

  Study needs to be repeated for non-ideal linac.

- ¥ Multiple sequential magnet failures (>1) result in large beam loss.

  Loss of both magnets in a cryomodule will cause machine downtime.

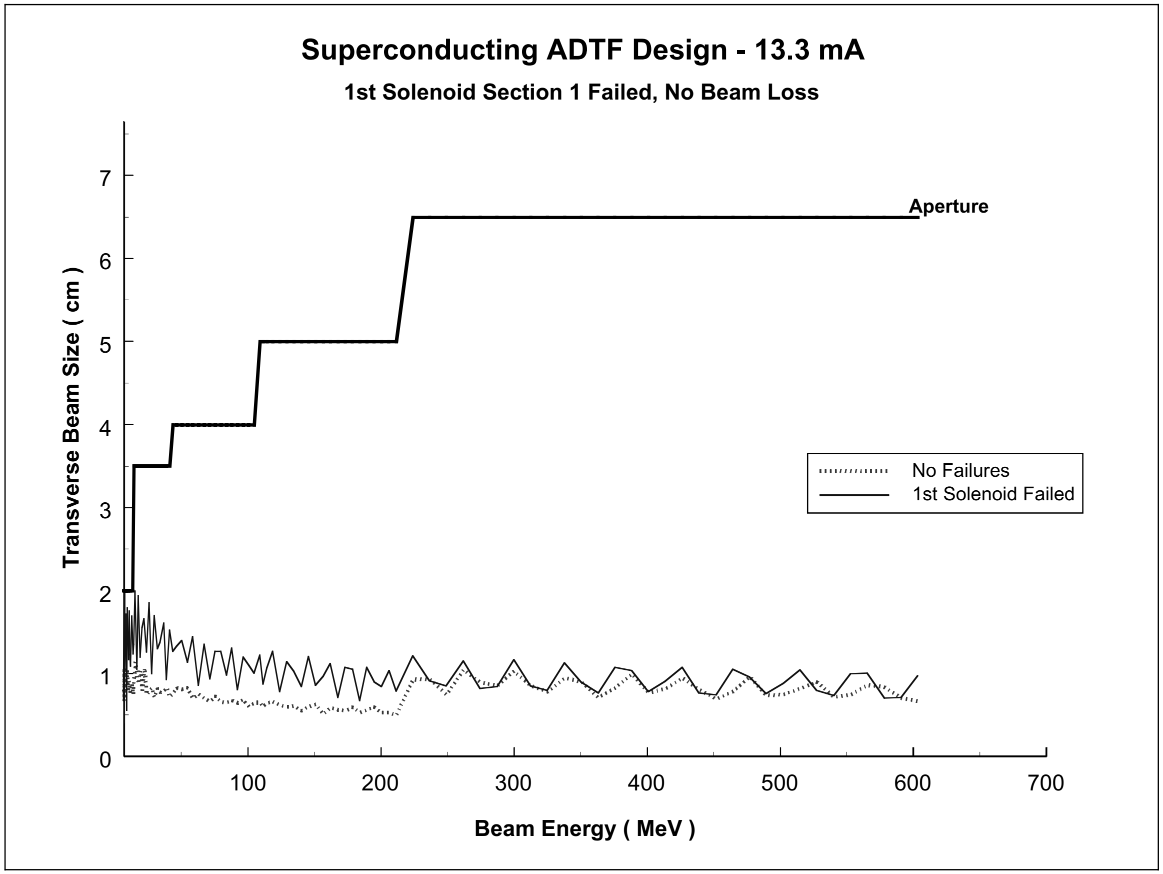
- ¥ Uncompensated single-cavity or RF module failures anywhere in the linac result in high beam loss.

  Compensation for loss of a cavity or loss of an RF module is <u>required</u> and <u>possible</u>.

  Example - Shift downstream cavity operating phases and increase amplitudes to restore beam energy.

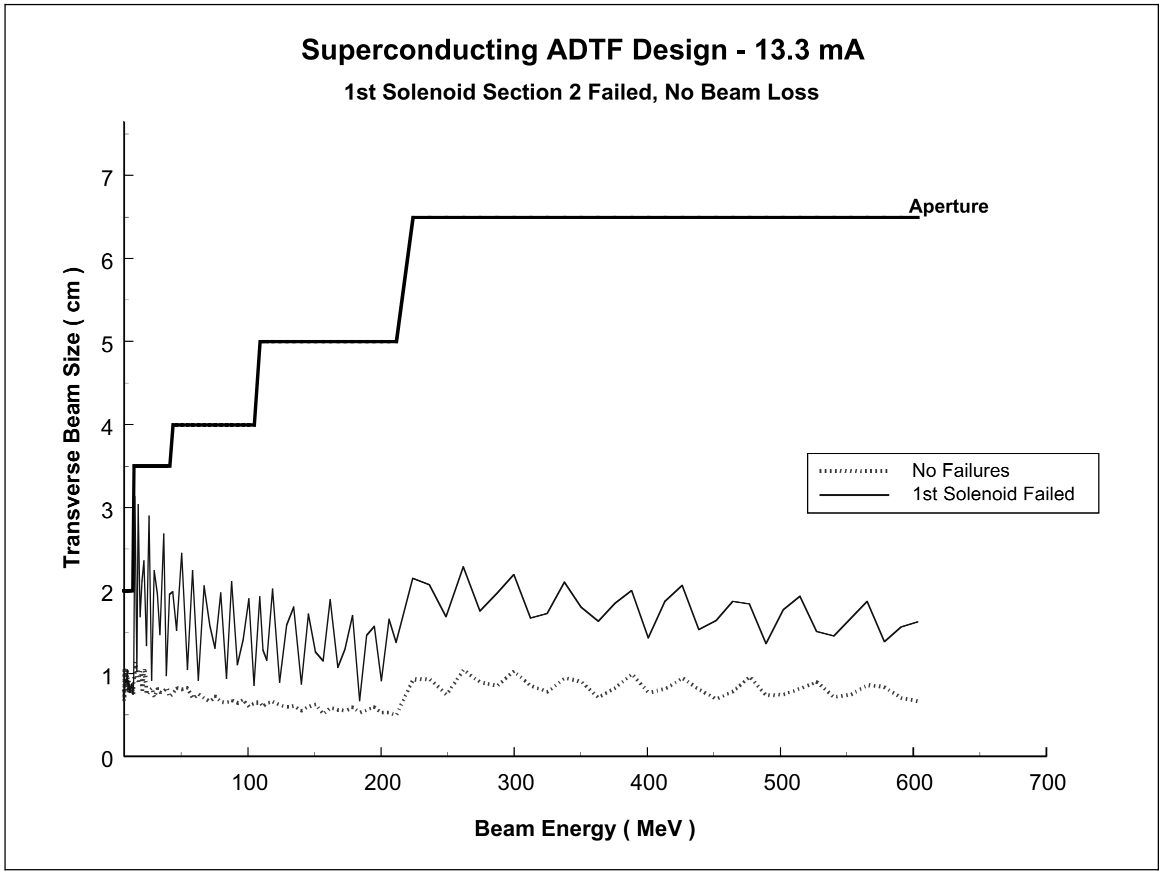
Fault / Failure Results (13.3 mA)

Maximum Beam Size -1st Solenoid Section 1 Failed



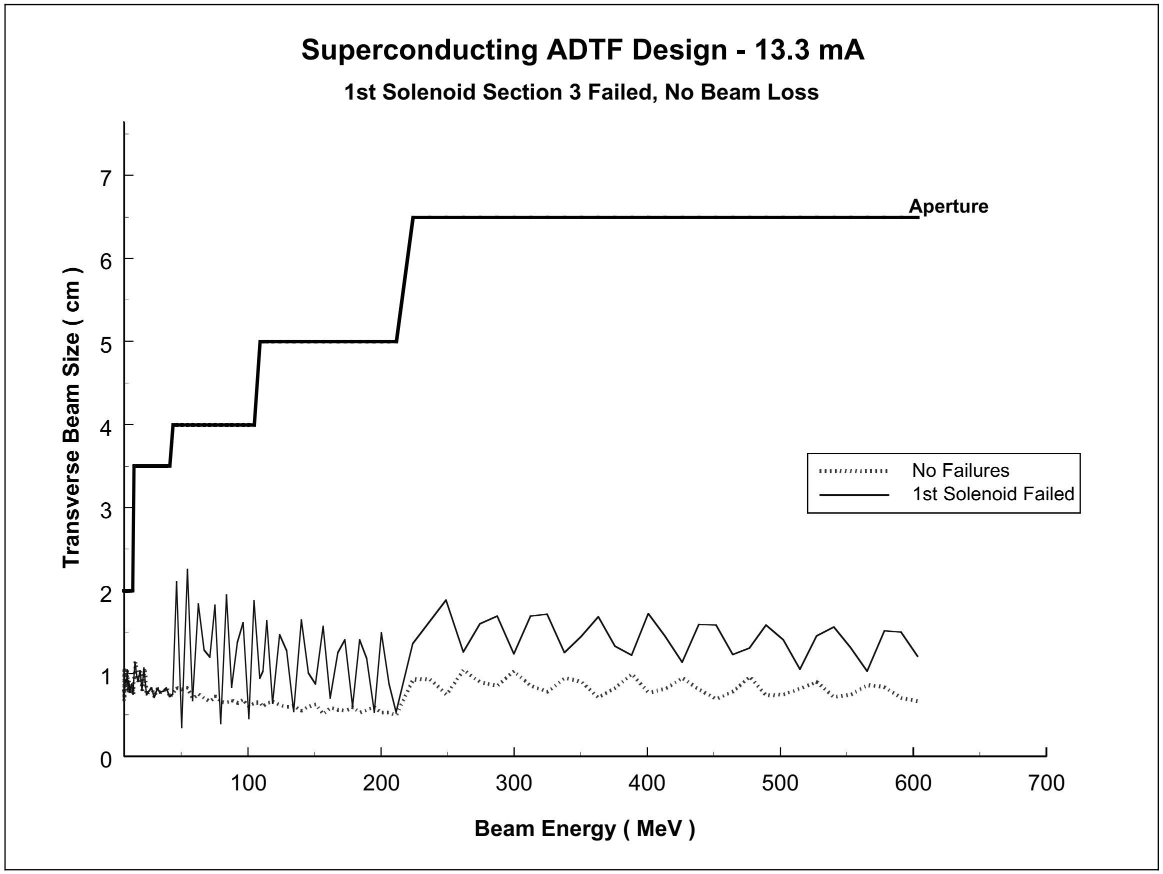
Fault / Failure Results (13.3 mA)
Maximum Beam Size - 1st Solenoid Section 2 Failed

AAA



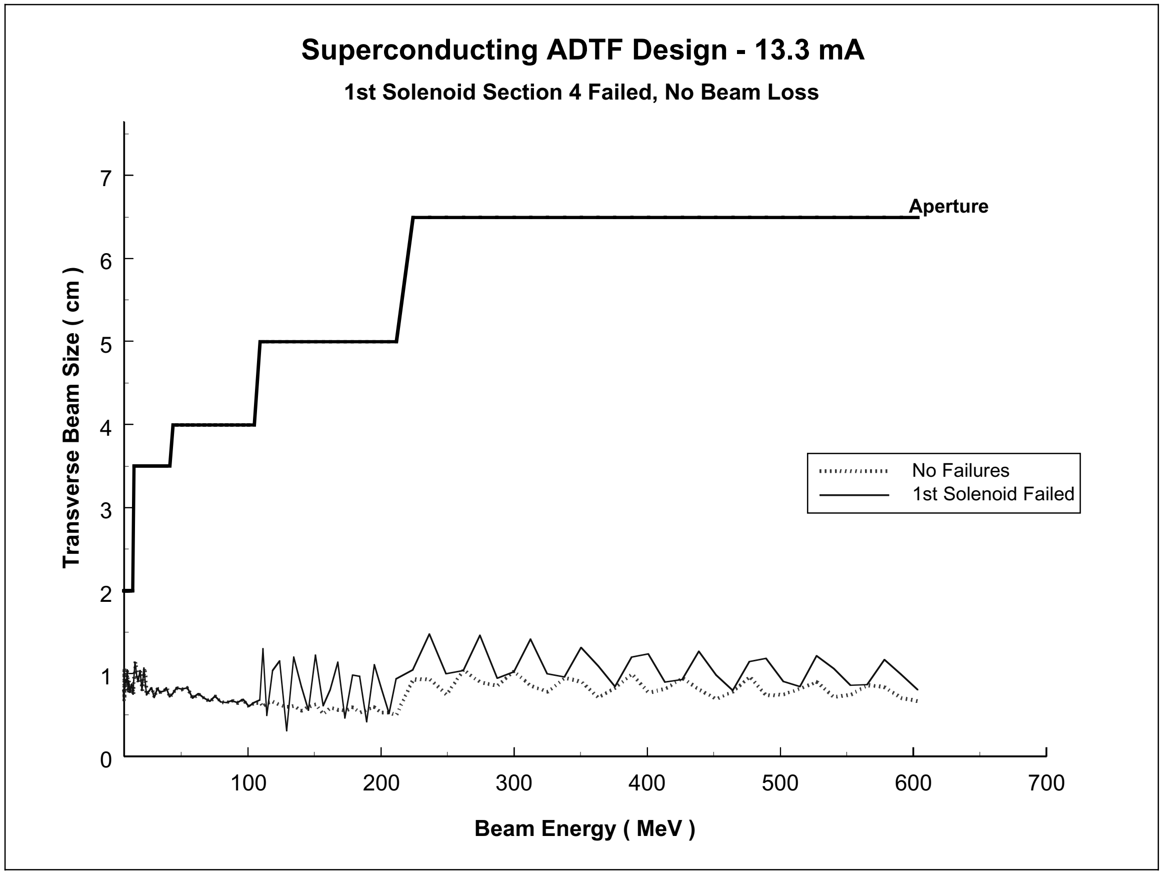
Fault / Failure Results (13.3 mA)

Maximum Beam Size - 1st Solenoid Section 3 Failed



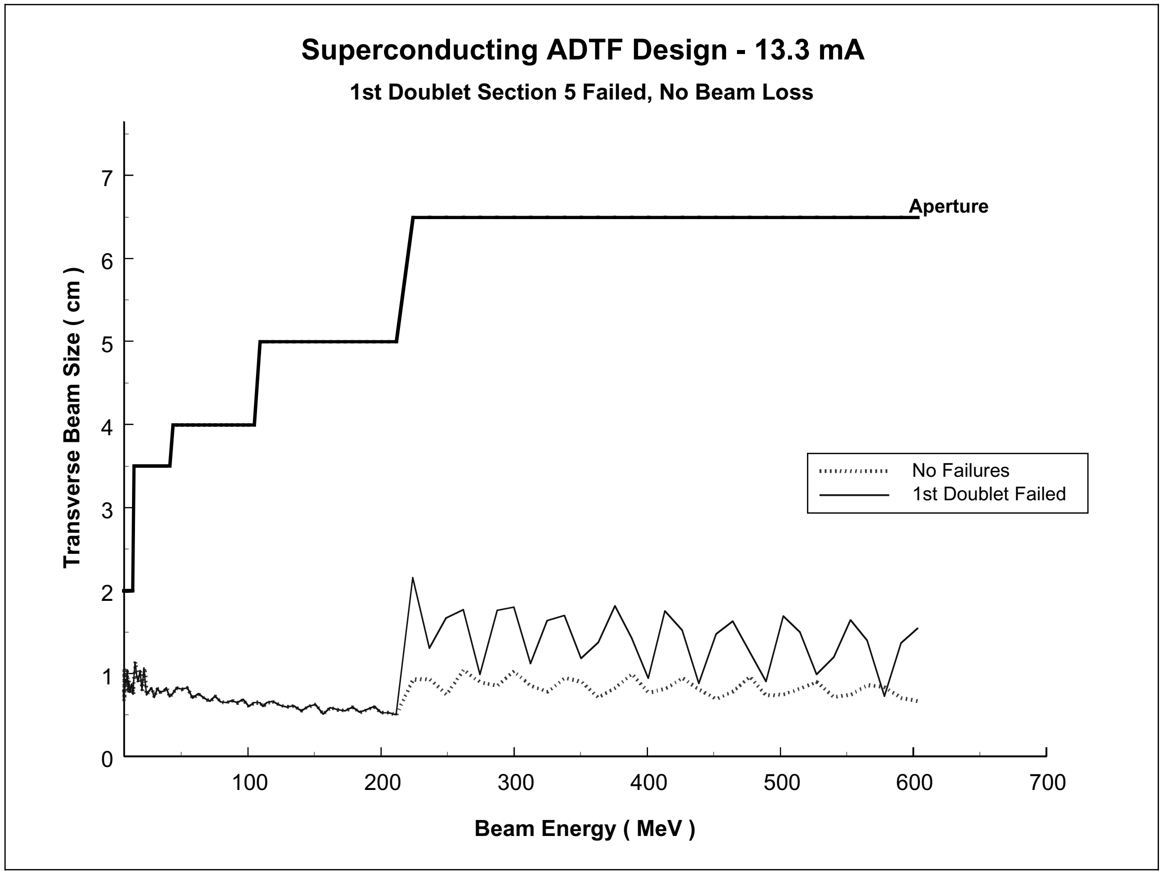
Fault / Failure Results (13.3 mA)

Maximum Beam Size - 1st Solenoid Section 4 Failed



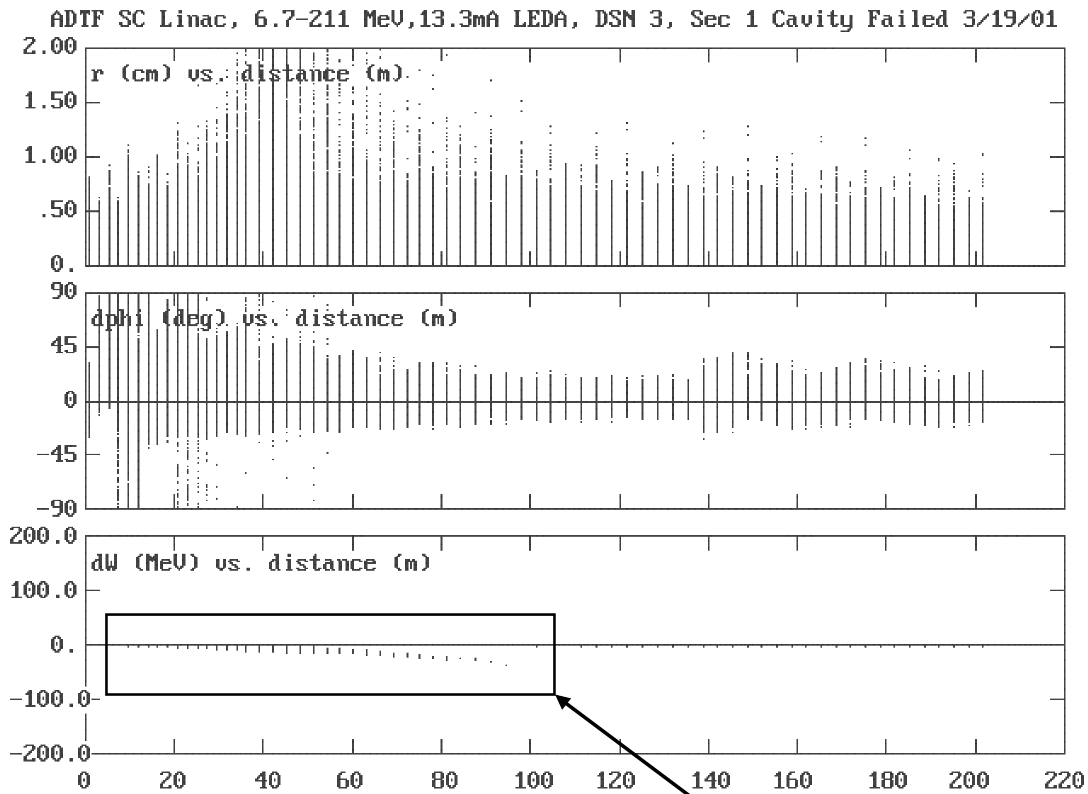
Fault / Failure Results (13.3 mA)

Maximum Beam Size - 1st Doublet Section 5 Failed



Fault / Failure Results (13.3 mA)

Uncompensated Section 1 RF Module Failure (1 Cavity Off)

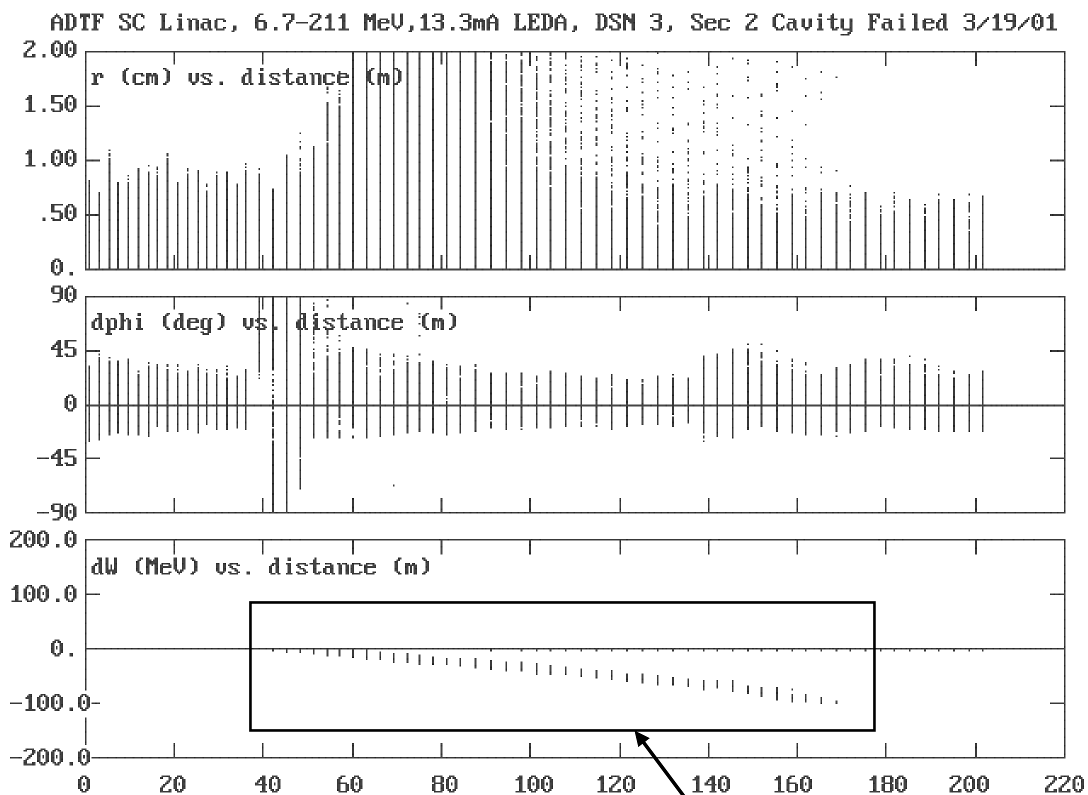


Particles lost from the RF bucket,

14% Beam Lost

Fault / Failure Results (13.3 mA)

Uncompensated Section 2 RF Module Failure (2 Cavities Off)



Particles lost from the RF bucket,

94% Beam Lost

Compensation of RF Module Failure

Option 1 -

Re-phase downstream cavities only

⇒ *Beam recaptured, output beam energy low.*

Option 2 -

Re-phase cavities and increase amplitudes (restore nominal beam energy)

⇒ *Restores final output beam energy.*

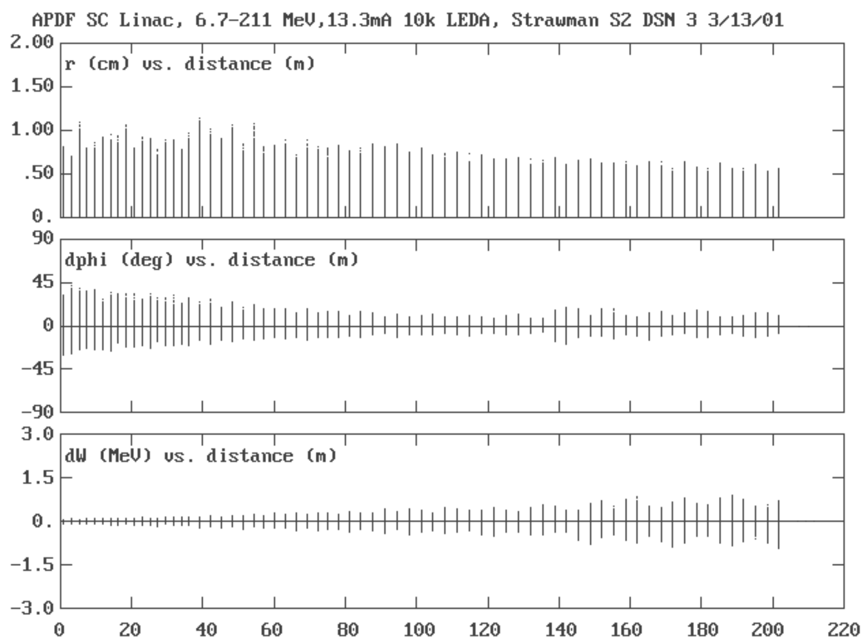
⇒ *Can use upstream, downstream or combination of cavities to restore nominal beam energy.*

⇒ *Number of cavities required to compensate depends on location of failed cavity (magnitude of lost energy-gain) and operating parameters of nearby cavities.*

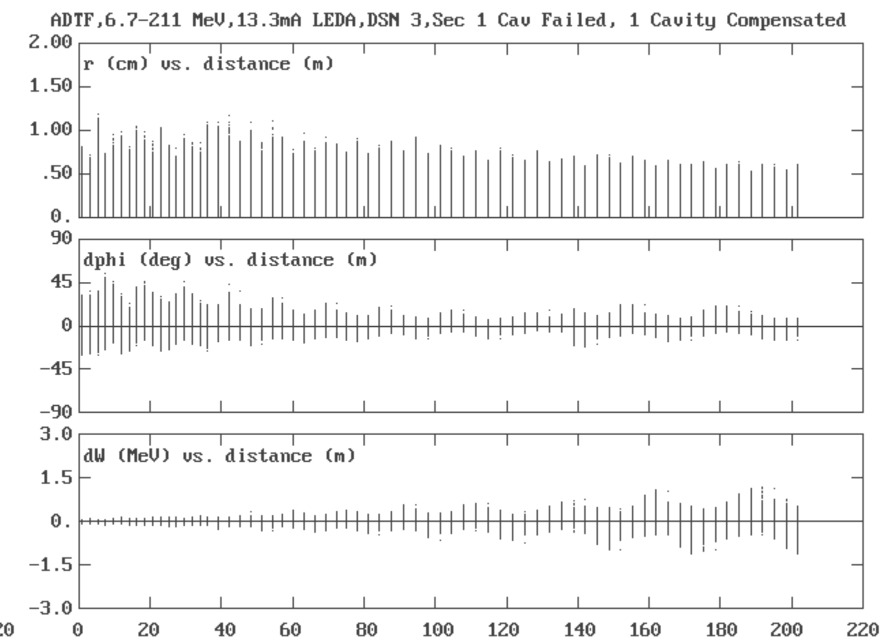
Fault / Failure Results (13.3 mA)

Compensated Section 1 RF Module Failure
(Single-Cavity Compensation)

No Failures



Failed and Compensated



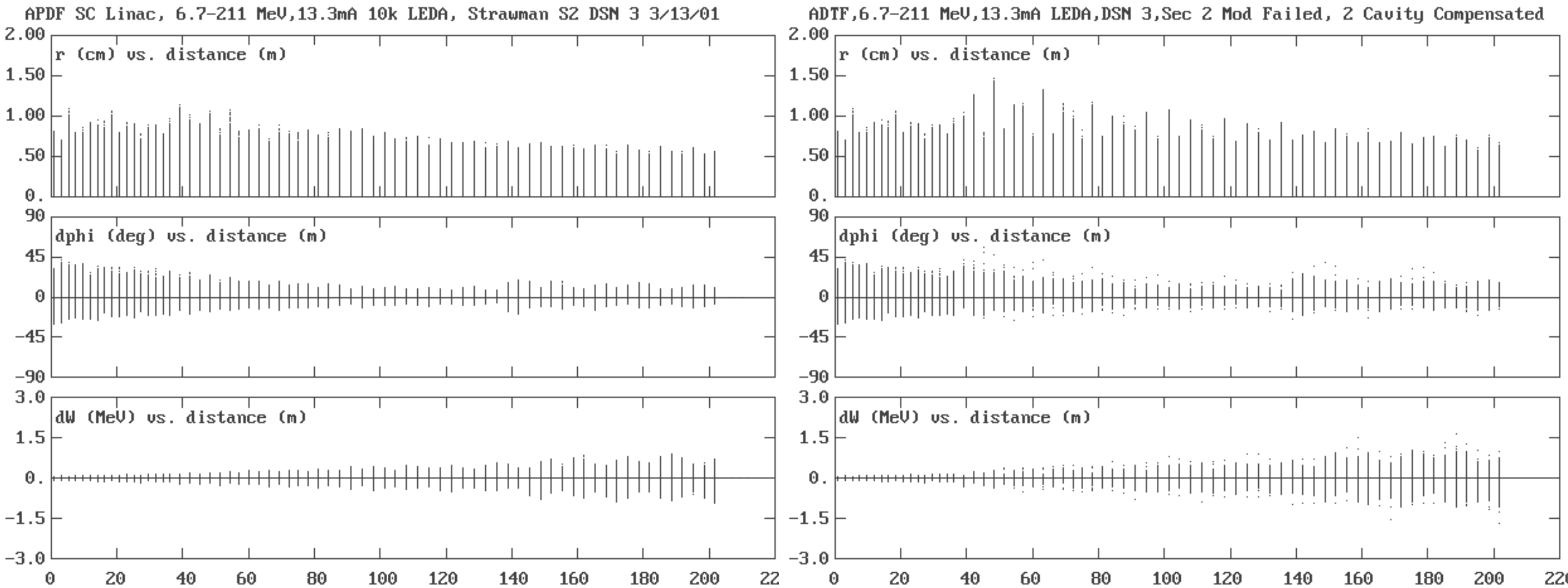
Fault / Failure Results (13.3 mA)

Compensated Section 2 RF Module Failure
(2-Cavity Compensation)

AAA

No Failures

Failed and Compensated

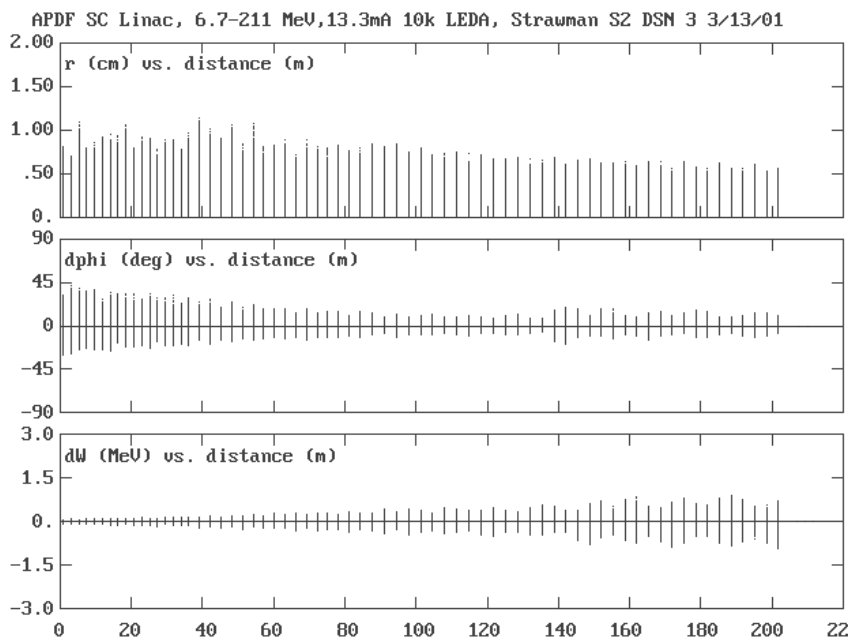


AAA

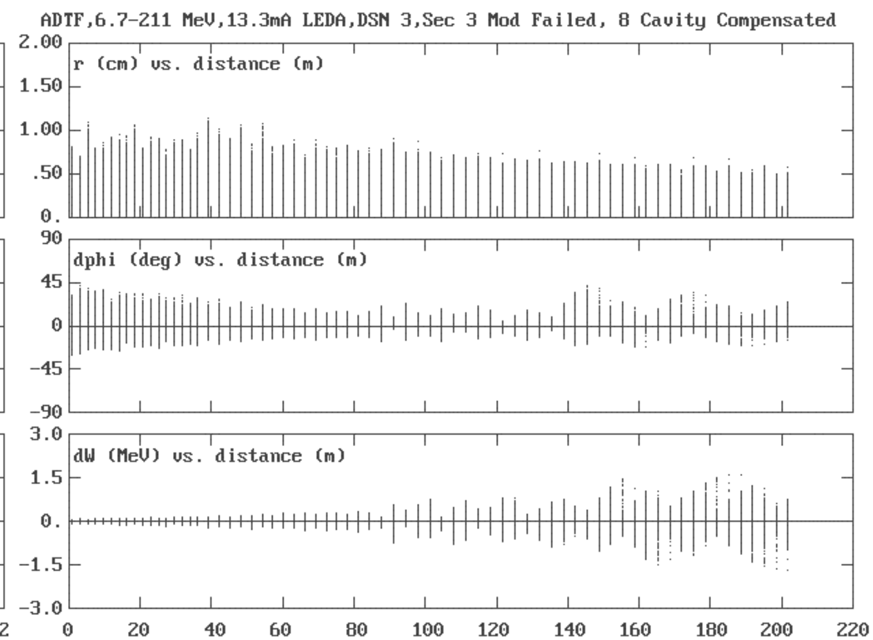
Fault / Failure Results (13.3 mA)

Compensated Section 3 RF Module Failure
(8-Cavity Compensation)

No Failures



Failed and Compensated

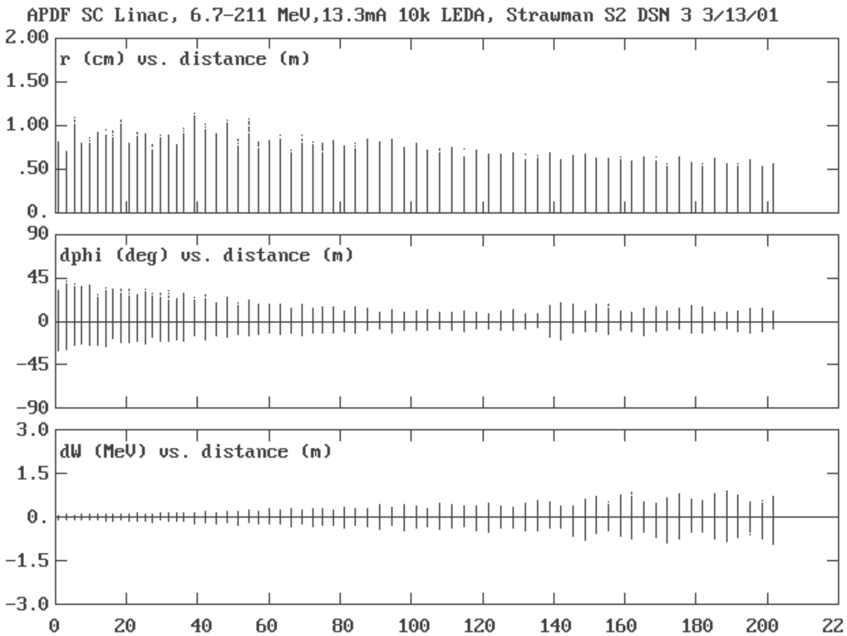


Fault / Failure Results (13.3 mA)

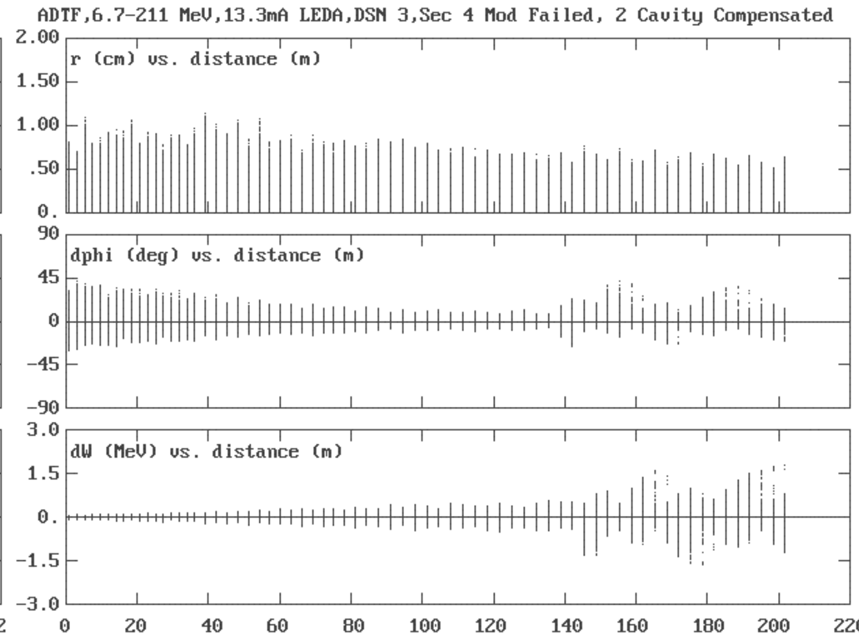
Compensated Section 4 RF Module Failure
(2-Cavity Compensation)

AAA

No Failures



Failed and Compensated



Summary

- Operational parameters are a compromise between good beam dynamics performance and efficient acceleration.

  Linac design is not yet optimized.

- Excellent performance at 13.3 mA.

  Aperture-to-rms beam size ratio comparable to APT.

  (Improved by ~ 40 % from 50-211 MeV)

- Simulations show 3 x 10^{-4} low-energy beam loss for 100 mA operation.

  Beam loss can be eliminated in next design iteration.

- Linac design is tolerant to major component failures:

  Loss of magnet or associated system components

  Loss of klystron or associated RF system components

  Loss of RF cavities

- Beam transport line to target must accommodate all beams.

AAA

SC RF System for ADTF

Dan Rees

4/11/01

ADTF Linac Review, April 10-12, 2001

AAA

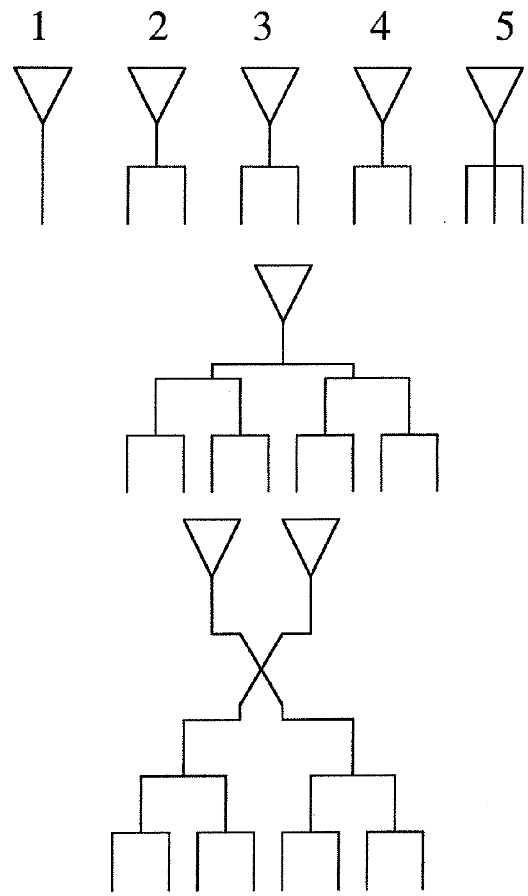
Outline

- Design Requirements
- Design Options
- RF System Design
- Design Details
- Comparison with the NC RF system

RF System Requirements - LE LINAC

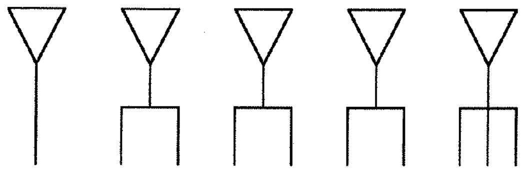
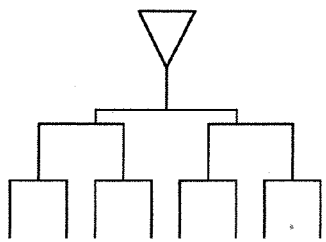
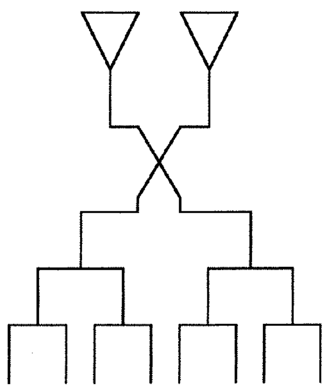
- Minimize the Beam Trips > .3 Seconds in Duration
  - "Instant" Redundancy
  - An architecture that offers high availability
  - Low RF and DC Fields
- High Efficiency
- Low Risk
- Low Cost

Considered Three Designs



Design 1	Sections	Can lose 1 RF station per section and keep running.
Design 2	All Sections	Achieve high availability through low parts count. Any RF system fails you shut down and fix it.
Design 3	All Sections	Can lose any one of a pair of RF systems and continue to operate with no beam interruption.

Design Comparison

		LE Linac Cost	RF Performance Issues
Design 1		$95 Million	
Design 2		$70 Million	Any RF/Cav failure is a long term beam interrupt. Poor individual cavity field amp And phase control. Can't quickly rephase for a failed Cavity.
Design 3		$94 Million	Poor individual cavity field amp And phase control. Can't quickly rephase for a failed Cavity.

AAA

Power Requirements

Sect	Cav Pwr (kW) 13.3 mA	Cav per Gen	Cav Pwr per Gen (kW)	No of Gen	Freq (MHz)	Rel Mult	Cntrl Margin Mult	Loss Mult	Rqd Gen Pwr (kW)	Gen Size (kW)	Totl RF Pwr (kW)	Gen Effic	AC/DC Effic	Total AC Power (kw)
1	5.2	1	5.2	32	350	1.1	1.1	0.85	7.4	10	320	.7	0.95	481
2	10.3	2	20.6	24	350	1.1	1.1	0.85	29.3	55	1320	.7	0.95	1985
3	18.1	2	36.2	24	350	1.1	1.1	0.85	51.5	55	1320	.7	0.95	1985
4	34.6	2	69.2	20	700	1.1	1.1	0.9	93.0	100	2000	.65	0.95	3238
5	56.1	3	168.3	31	700	1.1	1.1	0.9	226.3	250	7750	.65	0.95	12550

RF System Description

- 10 kW and 55 kW RF Stations are based on conventional, high reliability, broadcast systems.
- IOT used for the 10 kW and 55 kW.
- All RF systems are circulator protected.
- Klystrons operate at very moderate beam voltages. Should result in a low cost, reliable HVDC system.
  - 100 kW klystron, 35 kV
  - 250 kW klystron, 50 kV
- No mod anode on the klystrons
- 10% Control Margin
- 10% Reliability Margin
- 10 - 15% Loss Budget (15% would allow the use of coax for 10 kW system).

RF System Description (Cont.)

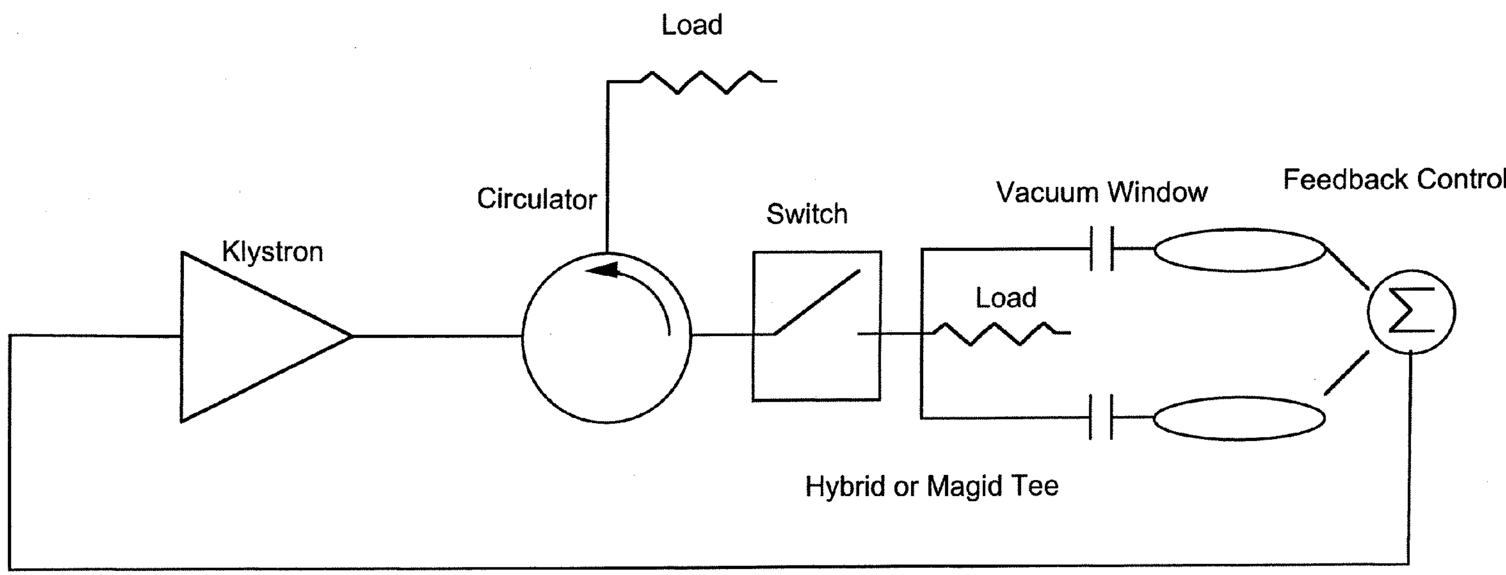
- One power supply and set of support electronics per RF station.
- One cavity field control system per klystron.
- A waveguide switch is included to isolate the klystron to allow for repair during beam operations.
- Slow, high power phase shifters included for phase matching.
- Failure of any RF system component only disables one klystron or IOT.

SC RF System Reliability/Availabilty

AAA

- A single RF station in any section of the LINAC can fail with a minimal (< 300 msec) interruption of the beam.
  - Cavities associated with the RF system detuned.
  - Subsequent cavities adjusted in phase and amplitude to make up for lost cavity.
  - Failed RF station is repaired, tested, and returned to service.
- RF system design allows for the operation of a single cavity in sections 2, 3, and 4 with one of the cavities failed and detuned.
- RF system design allows for the isolation of windows and all transmission line components if a failure is anticipated by increased arc rate or temperature. This is unique to the SC design and is not a feature of the NC design. Why - SC design can lose a cavity and detune, NC design needs all cavities.

RF Station Block Diagram (Section 2)



AAA

NC vs SC Comparisons Low Energy LIN AC Only

- Operating Cost / AC Power
  - SC 6.4 MW - **$2.1 Million** Yr Operating Cost (8000 hr, $.04/kWhr)
  - NC 62.3 MW - **$20 Million** Yr Operating Cost (8000 hr, $.04/kWhr)

- Installed RF Power
  - SC **5 MW** 32 - 10 kW, 48 -55 kW, 20 100 kW gens
  - NC **44 MW** 44, 1 MW gens

- RF System Cost (Not including facility cost - water, pwr,etc)
  - SC **$95 Million**
  - NC **$110 Million**

ADTF Linac Review, April 10-12, 2001

NC vs SC Comparisons
Low Energy LIN AC Only

- Cooling Water
  - SC **2,800 gpm**
  - NC **26,400 gpm**
- Power Dissipated in Waveguide (Assuming 10% Loss)
  - SC **500 kW**
  - NC **2.54 MW**
- Cost of Reliability
  - SC **10%** extra RF power
  - NC **50%** extra RF power

NC vs SC RF Risk Comparisons Low Energy LIN AC Only

AAA

- **RF System For SC Linac Considerably Lower Risk**
  - 1 MW Klystrons for NC vs 100 kW for SC
  - 1 MW Circulator for NC vs 100 kW for SC
  - RF Power for worst case SC window only about 20 % worst case of NC window
  - 95 kV klystron beam voltage for NC vs 35 kV for SC
    - More reliable klystron, power supply, high voltage diagnostics
    - Lower arc rate
  - SC Peak RF fields lower because of reduced power and reduced frequency.

- 1 MW CW Klystrons at 700 MHz exist. 3 were built for LEDA and all are in service. The cumulative operating hours on our 3 tubes is 2500 hours. We have had 1 transition and 1 collector that required repair. It took 10 bakeouts to deliver 3 tubes. One of our tubes has poor vacuum.

NC vs SC RF Risk Comparisons Low Energy LIN AC Only

- 350 MHz RF components are plentiful and the design is mature at 1 MW CW and at the low power levels required for the SC ADTF.

- 700 MHz RF components are scarce at 1 MW CW and have proven more difficult than 350 MHz because of the high energy density.

- The proximity of the SC ADTF RF system requirement to commercial broadcast units should insure plentiful suppliers and low risk, reliable, proven designs of components at the broadcast power level.

- The majority of the new business for klystron manufacturers is for low average power klystrons because most new high average power accelerators are superconducting.

Low Energy LINAC Facility Comparison

AAA

- Significant reduction in generator shielding requirements for SC.
- Number of Tunnel Components
  - SC Coupler
  - NC Coupler, Loads, Hybrids
- RF System Footprint (LE LINAC Only)
  - SC Approx. 6000 sq ft
  - NC Approx. 22,000 sq ft
- Interface to Power Grid
  - SC Lower power makes use of 480 VAC Service practical
  - NC PS feeds 4160 VAC or larger

ADTF Linac Review, April 10-12, 2001

TPO-RGN-1003

AAA

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

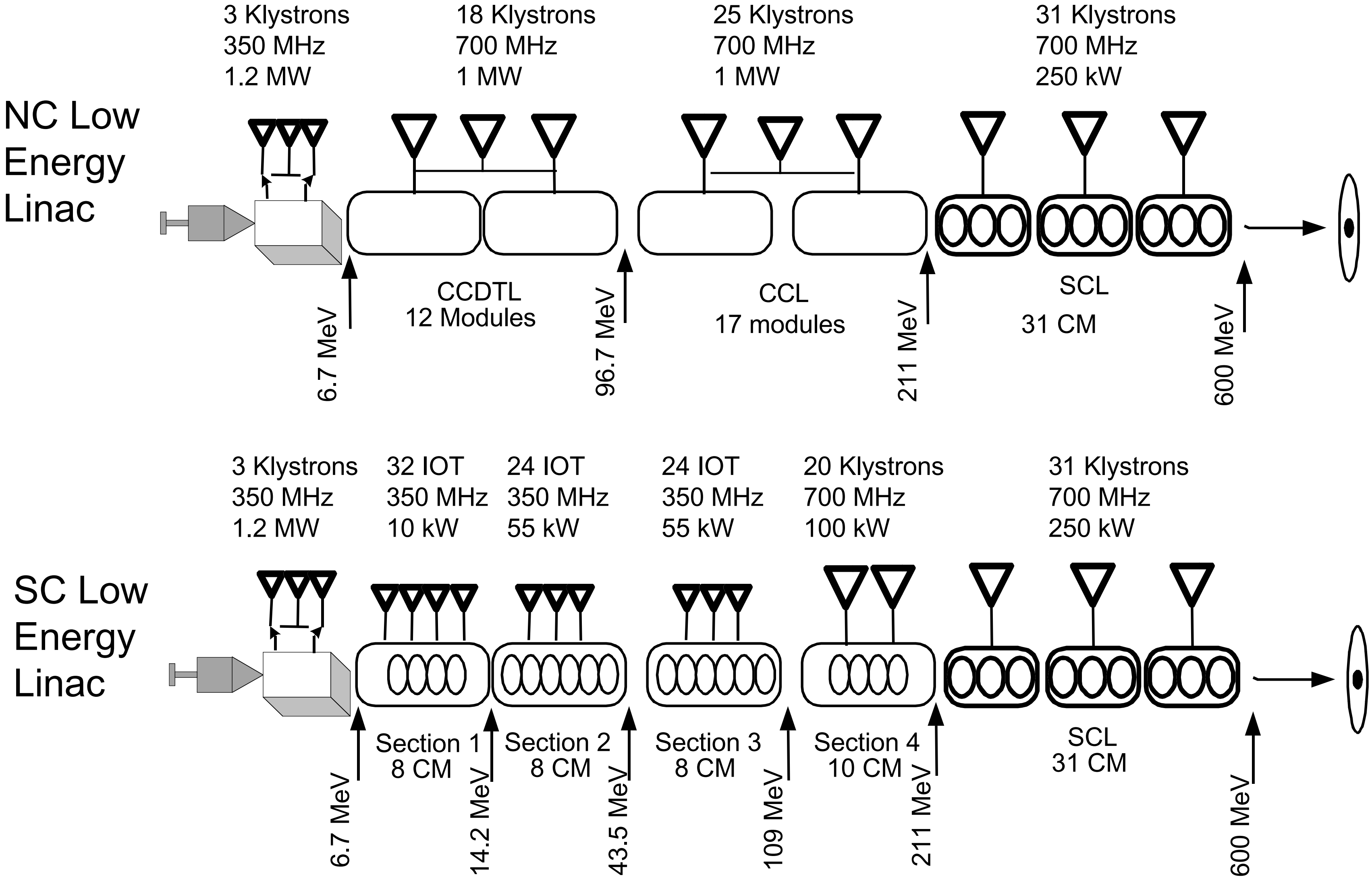
System Reliability

Kristen Kern

ADTF Linac Review, April 10-12, 2001

AAA

Comparison of Low Energy Linac Designs



ADTF Linac Review, April 10-12, 2001

Operational Assumptions

¥ Availability goals:

—75% overall plant availability during scheduled operation

—90% accelerator availabilty during scheduled operation

¥ Reliability goals:

—< 1000 trips per year, 0.3s to 100s in duration

—< 30 trips per year, >100s in duration

—Includes trips, not controlled shut down

¥ Operating cycle

—100 days operating

—10 days maintenance

—7960 scheduled operating hours per year

Definitions

AAA

- ¥ Components characterized with
  - —Failure rate λ_i (λ=1/mtbf)
  - —Repair time τ_i
- ¥ System
  - —Failure rate $\lambda = \Sigma\lambda_i$
  - —Number of failures in t: $N = \lambda t$
  - —Average repair time $\tau = \Sigma\lambda_i\tau_i/\Sigma\lambda_i$
  - —Availability $A=1/(1+\lambda\tau)$
- ¥ Redundancy
  - —Replace repair time with switchover time
  - —Done on component, assembly, or system level
- ¥ Calculations
  - —Long-term steady-state averages
  - —Do not include infant mortality

Rest of Accelerator Segment From APT Models

System	Availability (%)	Total Failures	0.3-100 sec (Trips)	>100 sec (Trips)
Injector	99.3	92	80	12
6.7-211 MeV Linac				
6.7-211 MeV Linac RF				
SCL	99.5	31	0	14
SCL RF	99.5	69	0	1
HEBT	99.6	14	0	5
Cryogenics	99.9	19	0	1
Diagnostics	99.8	1	0	<1
Accelerator Support	97.5	8	0	6
Total (w/o LEL)	**95.2**	**234**	**80**	**40**

RF System Data

MTBF data are estimates for 1 MW systems.

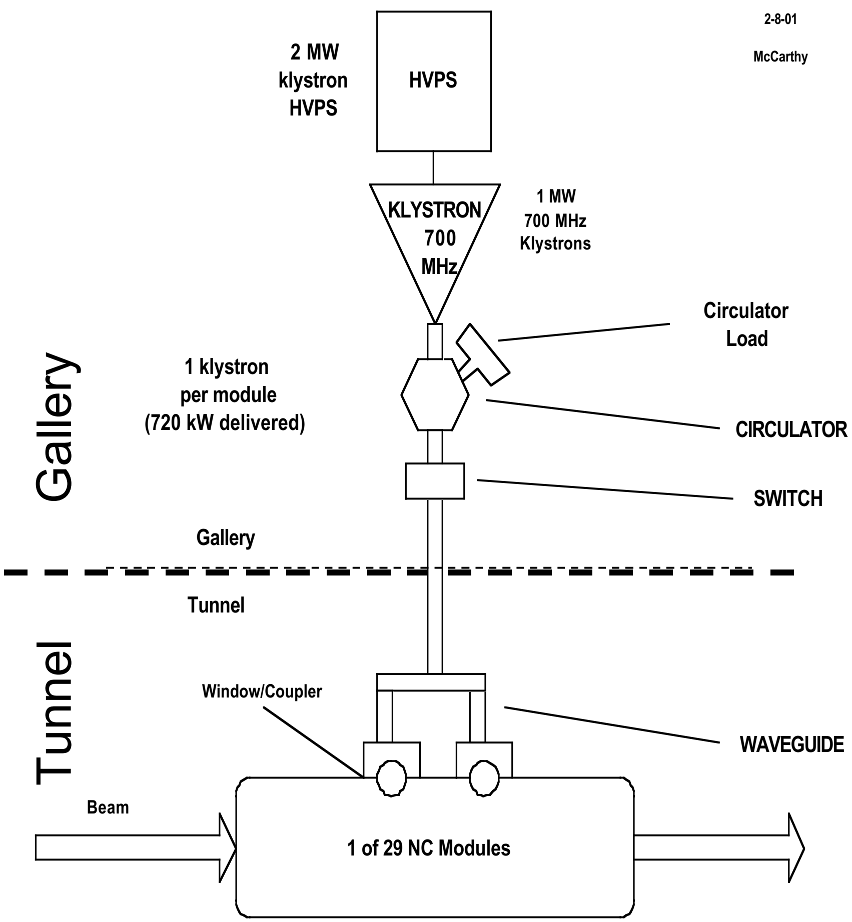
Component	MTBF (hr)	Source
Transmitter	8000	SNS/APT Vendor Analysis
HVPS	20,000	APT Vendor Analysis
Klystron	30,000	Engineering Judgement
Circulator	50,000	Engineering Judgement
Circulator Load	50,000	Engineering Judgement
Waveguide/water system	100,000	Engineering Judgement
Auto Waveguide Switches	40,000	Engineering Judgement
LLRF	50,000	Engineering Judgement
Fast Ferrite Wave Shifter	50,000	Engineering Judgement
Magic Tee Loads	50,000	Engineering Judgement
Remote Phase Shifter	50,000	Engineering Judgement
RF Window	100,000	Engineering Judgement

AAA

Single RF Station Repair Times

All times in hours

Transmitter	1	
HVPS	0.3	
Klystron	0.73	
Circulator	3.5	
Circulator Load	3.5	
Waveguide/water system	2	
LLRF	1	
Waveguide Switches	2	
Magic Tee Loads	8	
Remote Phase Shifter	8	
Waveguide/water system	8	
RF Window	8	NC
	16	SC

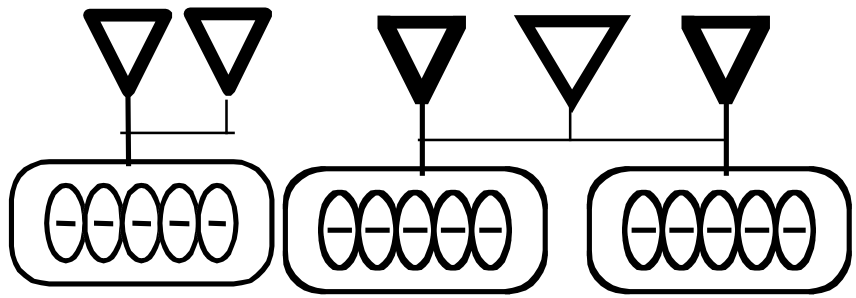


CCDTL/CCL

- ¥ Consists of 29 modules, all required
- ¥ Availability 98.6
  - —Potential for long outage due to coolant-vacuum leaks
- ¥ No short outages: 0.3 sec to 100 sec
- ¥ 22 long outages: >100 sec
  - —Magnet PS
  - —RCCS

CCDTL/CCL RF Power

29 modules
1 RF Station per module
1 module with a spare
1 spare for every 2 modules
44 total RF stations



Switch to spare takes approximately 60 seconds.

Failures per year	Impact
70 active RF stations	70 outages for switchover (60 sec)
14 tunnel components	14 outages >100 sec
7 hot spares	
	Availability = 98.6%

Probability of second failure is small

Superconducting Low Energy Linac

- ¥ 4 sections to 211 MeV
- ¥ Each section can operate with one RF station off line
- ¥ Ride through for
  - —Loss of RF power
  - —Loss of a single magnet
- ¥ 156 RF station failures

Section	Availability (%)	0.3 - 100 sec (trips)	>100 sec (trips)
1	99.7	0	4
2	99.7	0	4
3	99.7	0	4
4	99.6	0	5
RF	99.9	0	1
Total	**98.6**	**0**	**18**

Comparison of Systems

AAA

	Availability (%)	0.3-100 Sec (trips)	>100 sec (trips)
Goal	90	1000	30

Normal Conducting Linac

System	Availability (%)	Total Failures	0.3-100 Sec (trips)	>100 sec (trips)
Rest of Accelerator	94.7	234	80	40
6.7-211 MeV Linac	96.6	192	0	22
RF	98.6	90	70	14
Total	**90.2**	**516**	**150**	**76**

Superconducting Linac

System	Availability (%)	Total Failures	0.3-100 Sec (trips)	>100 sec (trips)
Rest of Accelerator	94.7	234	80	40
6.7-211 MeV Linac	98.7	71	0	17
RF	99.9	156	0	1
Total	**93.4**	**461**	**80**	**58**

Summary

- ¥ Requirements
  - —Availability Goal - both designs meet
  - —Outages 03 sec to 100 sec - both designs meet
  - —Outages >100 sec
    - ¨ Neither design meets
    - ¨ SC design has fewer failures
- ¥ Results reflect
  - —Long term, steady-state behavior
  - —Not commissioning/infant mortality
  - —No detailed modeling of other systems

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

ADTF COST COMPARISON STUDY NORMAL vs SUPERCONDUCTING

J. Rathke for T. Myers
Advanced Energy Systems, Inc.
Medford, NY

Study Objective

- To compare & contrast the cost of the ADTF NC & SC linac configurations between 6.7MeV and 211 MeV.
  - assume the design, fabrication, and installation activities will be achieved by an industrial prime contractor with Laboratory assistance (APT model)
  - include RELEVANT linac secondary systems
  - only consider design through to the beginning of system commissioning project phases
    - » ED&D, startup and operations for both options excluded from this comparison
  - focus is to identify COST DIFFERENCES between the options
- Differences in project management resources expressly excluded from the analysis

Study Participants

- Los Alamos
  - R. Garnett, R. Gentzlinger, D. Gilpatrick, P. Kelley, F. Krawczyk, M. Lynch, D. Rees, A. Regan, D. Schrage, E. Schmierer, R. Sheffield, M. Thuot, T. Wangler, R. Wood
  - Many others
- Advanced Energy Systems, Inc.
  - T. Myers, E. Peterson, J. Rathke

Other Contributors

- **National Laboratories**
  - ANL - RIA project, LBNL - SNS Project
- **Industry**

– RF System Components	Thales (formerly Thompson CSF), Marconi (formerly EEV), CPI (formerly Varian), Continental, Maxwell, Mega Industries
– Cryosystem Components	ProQuip, Linde Kryotechnik AG, Air Liquide, Cryomagnetics
– Niobium	Wah Chang
– Niobium Seamless Tubing Niobium Formed Spokes	Metal Technology, Inc.
– Stainless Steel Type 304	Sterling Aircraft Materials Ltd.
– OFE Copper (ASTM F-68)	Copper & Brass Sales, Inc.
– Hydroforming	Aero-Trades Manufacturing
– Electron Beam Welding	Sciaky, Inc.
– Brazing (Nb to SST)	Martin Kurz & Company, Inc.
– Electroplating (Ni on Nb)	Epner Technology, Inc.
– Superconducting Solenoids	American Magnetics, Inc.

Cost Estimating Approach

- **Perform point costing where possible.**
  - **Time and resource constraints force the use of stored work product at some level in most cases.**
- **Utilize appropriate personnel and supporting cost databases available for each WBS element.**

WBS TITLE	RESPONSIBLE ORGANIZATION(S)	SUPPORTING PROGRAMS
Engineering Design / Installation	Los Alamos / AES	APT, LEDA, SDI…
Accelerator Structures		
CCDTL / CCL	AES	SNS, APT
Spoke Resonators	AES	RIA
Elliptical Cavities	Los Alamos	ED&D
Couplers	Los Alamos	ED&D
RF Power System	Los Alamos	APT, SNS, LEDA
Cryostats & Cryo Systems	Los Alamos	ED&D, APT
Diagnostics	Los Alamos	APT, LEDA, SNS
Vacuum Systems	AES / Los Alamos	ED&D, LEDA, APT
Resonance Control Cooling	AES	SNS
Support and Alignment	AES / Los Alamos	LEDA, APT
Conventional Facilities	AES / Los Alamos	APT, SNS

- **Supporting programs have actual hardware and/or estimates that have been formally peer reviewed and/or ICE'd.**

Assumptions - I *

- **FTE weeks/year: 47**
- **FTE hours/year:**
  - Los Alamos: 1750
  - Industry: 1824
- **Linac lengths: NC = 182.0 m, SC = 205.2 m**
- **Costs to be collected as labor and/or procured material & services**

Labor Categories	$k/FTE-years
LANL_TSM	$200.00
LANL_TECH	$110.00
PC_TSM	$230.00
PC_Tech	$95.00
PC_Craft	$76.00
SUB_TSM	$199.00
SUB_Tech	$109.00
SUB_Craft	$70.00

* Ref: LANSCE-1:01-010, 1/26/01

Assumptions - II *

- Project Contingency - 30% for both designs
- Project phase duration (per ADTF Project Schedule 3/7/01)
  - design 4 years
  - component fabrication 3 years (2 year overlap w/ design)
  - installation & checkout 2 years

- ADTF infrastructure support
  - personnel support $25k/FTE-year
  - CAD support $23k/FTE-year (design phase only)
  - procurement tax 15% on all purchased M&S

* Ref: ADTF Cost Meeting Notes, 3/22/01

Assumptions - III *

- Learning curve (component fabrication phase)
  - applied to touch labor only (NOT material)
  - 9% savings for each doubling in production quantity (91% LC)
    - » CCDTL supplied by one organization
    - » CCL supplied by one organization
    - » Each SC cavity type (spoke and elliptical) supplied by separate organization
    - » Each SC cryostat type (spoke and elliptical cavity) supplied by separate organization
    - » No learning curve applied to RF & Cryoplant systems
    - » Niobium = $294-237/lb, Copper = $4.50/lb, Stainless = $2.50/lb
- No learning curve applied to design or installation & checkout phases

* Ref: ADTF Cost Meeting Notes, 3/22/01

Assumptions - IV *

- Raw Material, Braze Heats, E-beam welds
  - based on Los Alamos experience a 25% additional allocation in the listed categories was applied
- Civil Structure Costs
  - composite rate for each building type based upon APT, SNS, and RIA Project costs for similar structures
  - no difference in RF hall size considered
    - » size more dependant on linac length
    - » but: cooling of RF waveguide in NC case included
- EPICS control system costs considered approximately the same (no costs included in this study)

* Ref: ADTF Cost Meeting Notes, 3/22/01

NC Linac Configuration (2/16/01)

ADTF Proposal (Approximation) for 2/16/01

Partitioning for: maximum 2- 840 kW klystrons per module at 100 mA
min. 13.3 mA w/ 1- 725 kW klystron per module

Eliminate 3-gap cavities
Use 8BL lattice throughout
ramp to 1.5MV/m

Nominal Fi 211 MeV

						ADTF = 13.3 mA, 725 kW per kly			Upgraded to 100 mA, 840 kW max per kly.								
Module Number	Type of RF struct.	Module Length (m)	Total Length (m)	Module Cu Power (MW)	Final Energy (MeV)	Klystrons in this Module	Beam power (MW)	Module Power (MW)	Klystrons in this Module	Beam power (MW)	Module Power (MW)	Reflected Power (MW)	Power per kly. (MW)	Ending Segment Number	number segments and quads	Accel. Cavities /module	Total Cavities /module
1	1 X 2-gap	10.70	10.70	0.49	9.87	1	0.042	0.528	1	0.317	0.803	0.036	0.838	48	48	48	109
2	1 X 2-gap	11.53	22.23	0.63	15.49	1	0.075	0.709	2	0.562	1.197	0.084	0.640	90	42	42	97
3	1 X 2-gap	9.34	31.57	0.63	21.89	1	0.085	0.717	2	0.640	1.272	0.107	0.690	118	28	28	65
4	1 X 2-gap	7.74	39.31	0.60	28.67	1	0.090	0.694	2	0.677	1.282	0.124	0.703	138	20	20	49
5	2 X 2-gap	8.93	48.24	0.56	38.31	1	0.128	0.685	2	0.964	1.521	0.158	0.839	158	40	80	159
6	2 X 2-gap	6.98	55.22	0.55	47.18	1	0.118	0.668	2	0.887	1.437	0.221	0.829	172	14	28	55
7	2 X 2-gap	7.09	62.31	0.54	56.38	1	0.122	0.661	2	0.920	1.459	0.221	0.840	185	13	26	51
8	2 X 2-gap	7.05	69.36	0.57	65.54	1	0.122	0.688	2	0.916	1.482	0.181	0.831	197	12	24	47
9	2 X 2-gap	6.24	75.60	0.51	73.65	1	0.108	0.623	2	0.811	1.326	0.198	0.762	207	10	20	39
10	2 X 2-gap	6.57	82.17	0.56	82.18	1	0.113	0.669	2	0.853	1.408	0.204	0.806	217	10	20	39
11	2 X 2-gap	6.18	88.35	0.53	90.20	1	0.107	0.641	2	0.803	1.337	0.189	0.763	226	9	18	35
12	2 X 2-gap	5.70	94.05	0.50	97.61	1	0.098	0.601	2	0.741	1.244	0.171	0.707	234	8	48	95
13	6-cell CCL	5.15	99.20	0.60	104.29	1	0.089	0.686	2	0.669	1.266	0.122	0.694	241	7	42	83
14	6-cell CCL	5.29	104.50	0.60	111.17	1	0.091	0.692	2	0.687	1.288	0.128	0.708	248	7	42	83
15	6-cell CCL	5.44	109.93	0.60	118.23	1	0.094	0.697	2	0.706	1.309	0.134	0.722	255	7	42	83
16	6-cell CCL	5.58	115.51	0.60	125.47	1	0.096	0.700	2	0.724	1.328	0.141	0.734	262	7	42	83
17	6-cell CCL	5.71	121.22	0.61	132.88	1	0.099	0.705	2	0.742	1.348	0.147	0.747	269	7	42	83
18	6-cell CCL	5.00	126.22	0.55	139.38	1	0.086	0.632	2	0.650	1.196	0.125	0.660	275	6	36	71
19	6-cell CCL	5.10	131.32	0.60	146.00	1	0.088	0.686	2	0.662	1.260	0.120	0.690	281	6	36	71
20	6-cell CCL	5.19	136.52	0.60	152.74	1	0.090	0.687	2	0.674	1.272	0.124	0.698	287	6	36	71
21	6-cell CCL	5.29	141.80	0.60	159.61	1	0.091	0.689	2	0.686	1.284	0.128	0.706	293	6	36	71
22	6-cell CCL	5.38	147.18	0.60	166.59	1	0.093	0.690	2	0.698	1.295	0.133	0.714	299	6	36	71
23	6-cell CCL	4.55	151.73	0.53	172.50	1	0.079	0.605	2	0.591	1.117	0.108	0.613	304	5	30	59
24	6-cell CCL	4.61	156.34	0.53	178.48	1	0.080	0.614	2	0.599	1.133	0.110	0.621	309	5	30	59
25	6-cell CCL	4.67	161.01	0.53	184.55	1	0.081	0.615	2	0.607	1.141	0.112	0.627	314	5	30	59
26	6-cell CCL	4.73	165.74	0.53	190.69	1	0.082	0.613	2	0.614	1.145	0.116	0.631	319	5	30	59
27	6-cell CCL	4.79	170.53	0.53	196.91	1	0.083	0.614	2	0.622	1.153	0.118	0.636	324	5	30	59
28	6-cell CCL	4.85	175.38	0.53	203.20	1	0.084	0.617	2	0.629	1.163	0.121	0.642	329	5	30	59
29	6-cell CCL	4.90298	180.2832	0.530222	209.5692	1	0.085	0.615	2	0.637	1.167	0.124	0.645	334	5	30	59

SC Linac Configuration (LANSCE-1:01-034, 3/15/01)

	Section 1	Section 2	Section 3	Section 4
Frequency (MHz)	350	350	350	700
betag	0.175	0.2	0.34	0.48
L-cav (active) (m)	0.100	0.196	0.333	0.514
L-cav (physical) (m)	0.200	0.296	0.433	0.900
L-mag2cav (m)	0.300	0.300	0.300	0.300
L-drift1 (m)	0.300	0.300	0.300	0.100
L-drift2 (m)	1.113	1.113	1.113	1.088
L-magnet (m)	0.150	0.150	0.150	0.250
L-w2c1 (m)	0.394	0.394	0.394	0.394
L-w2c2 (m)	0.419	0.419	0.419	0.394
L-warm	0.300	0.300	0.300	0.300
L-cryomodule (m)	4.226	5.802	6.624	6.183
L-cryoperiod (m)	4.526	6.102	6.924	6.483
L-focusing period (m)	2.263	3.051	3.462	3.338
DW/cav (MeV)	0.08 to 0.353	0.335 to 0.778	0.867 to 1.398	0.950 to 2.727
Win,section (MeV)	6.7	14.174	43.544	109.043
Wout,section (MeV)	14.174	43.544	109.043	211
DW/section (MeV)	7.474	29.37	65.499	101.957
Cav/cryomodule	4	6	6	4
Cav/section	32	48	48	40
No. of cryomodules	8	8	8	10
Section Length (m)	36.208	48.816	55.392	64.83
No. Cavities/RF Generator	1	2	2	2
Beam Current (mA)	13.3	13.3	13.3	13.3
Coupler Power (kW)	5.2	10.3	18.1	34.6
Bore Radius (cm)	2.0	3.5	4.0	5.0
Structure Type	2-gap spoke	3-gap spoke	3-gap spoke	5-cell elliptical
Average RE Gradient	0.206	0.602	1.182	1.573

AAA

NC Linac Level 3 WBS
(95 total cost elements considered)

WBS Level 1	2	3	4	Name
1.0				NC Configuration Option
	1.01			Preliminary & Final Design
		1.01.01		Linac Structures
		1.01.02		RF Power
		1.01.03		Thermal Control System
		1.01.04		Civil Structures
	1.02			Linac Structures
		1.02.01		CCDTL
		1.02.02		CCL
		1.02.03		Focusing Magnets
		1.02.04		Diagnostics
		1.02.05		Vacuum Systems
		1.02.06		Structural Support & Alignment
	1.03			RF Power
		1.03.01		700 MHZ System
	1.04			Thermal Control System
		1.04.01		Pumps
		1.04.02		Heat Exchangers
		1.04.03		Fluid Lines & Connectors
		1.04.04		Temperatrue Mixing System
	1.05			Civil Structures
		1.05.01		Linac Tunnel
		1.05.02		Waveguide cooling system
		1.05.03		Prime Power
	1.06			Installation & Checkout
		1.06.01		Linac Structures
		1.06.02		RF Power
		1.06.03		Resonance Control System
		1.06.04		Civil Structures

SC Linac Level 3 WBS
(96 total cost elements considered)

WBS Level				
1	2	3	4	Name
1.0				SC Configuration Option
	1.01			Preliminary & Final Design
		1.01.01		Linac Structures
		1.01.02		RF Power
		1.01.03		Cryogenic Supply System
		1.01.04		Civil Structures
	1.02			Linac Structures
		1.02.01		Matching Section
		1.02.02		Spoke Cavities
		1.02.03		Elliptical Cavities
		1.02.04		Couplers
		1.02.05		Focusing Magnets
		1.02.06		Diagnostics
		1.02.07		Cryostat
	1.03			RF Power
		1.03.01		350 & 700 MHZ System
	1.04			Cryogenic Supply
		1.04.01		Cryoplant Substation & Switchgear
		1.04.02		Cold Boxes, Compressor Systems, Storage Systems, Controls
		1.04.03		Transfer Lines & Inserts
	1.05			Civil Structures
		1.05.01		Linac Tunnel
		1.05.02		Cryoplant Building
	1.06			Installation & Checkout
		1.06.01		Linac Structures
		1.06.02		RF Power
		1.06.03		Cryogenic Supply
		1.06.04		Civil Structures

Level 2 Comparison

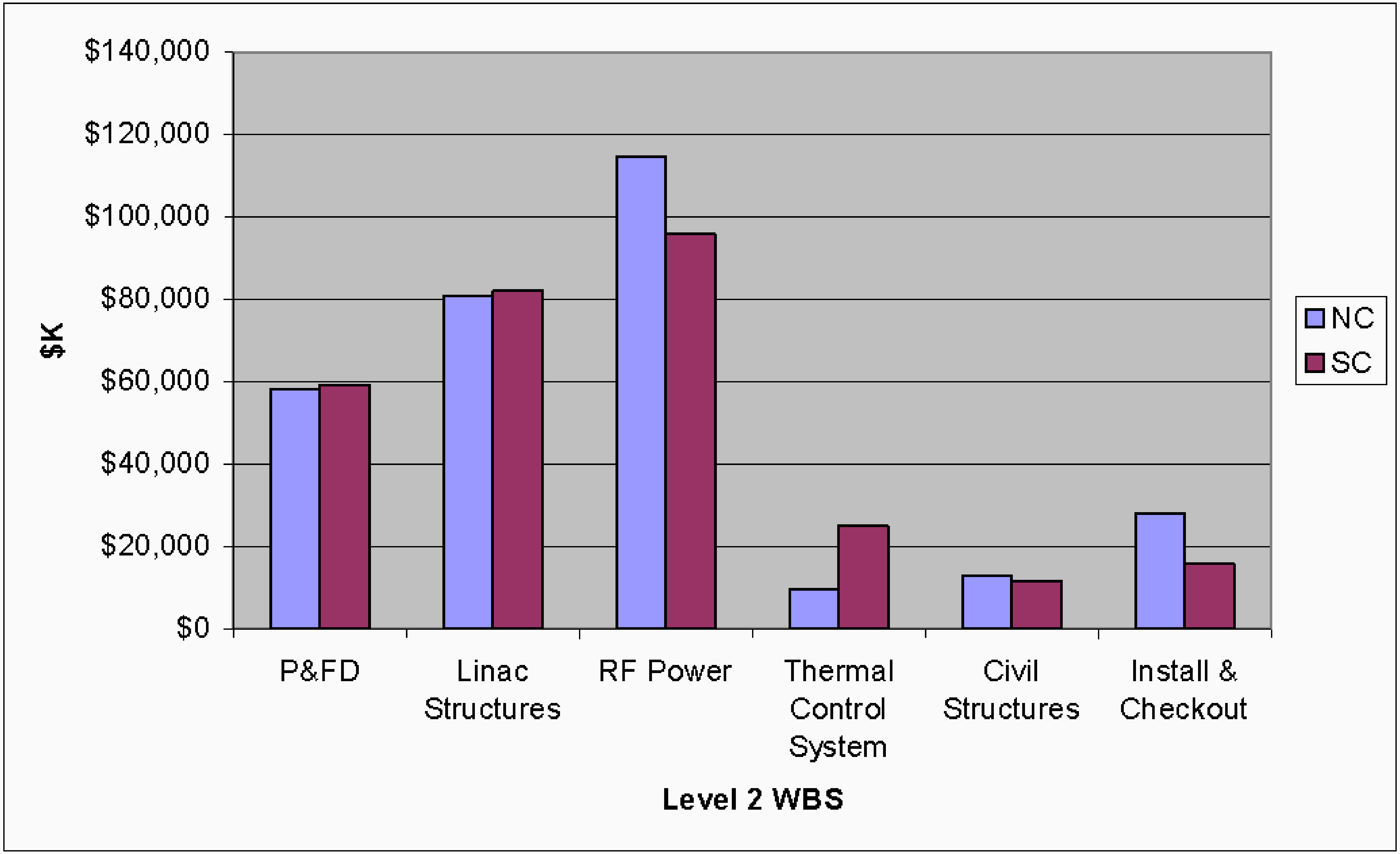
AAA

WBS Level 1	2	3	4	Name	TOTAL with contingency ($k)	Contingency ($k)	Total w/o cont($k)	Subtotals: Labor ($k)	Subtotals: M&S ($k)
1.0				NC Configuration Option	$395,622	$91,297	$304,325	$114,488	$187,968
	1.01			Preliminary & Final Design	$75,714	$17,473	$58,242	$38,222	$18,151
	1.02			Linac Structures	$105,105	$24,255	$80,850	$40,606	$40,244
	1.03			RF Power	$149,268	$34,446	$114,822	$11,325	$103,497
	1.04			Thermal Control System	$12,368	$2,854	$9,514	$890	$8,624
	1.05			Civil Structures	$16,784	$3,873	$12,911	$105	$12,807
	1.06			Installation & Checkout	$36,382	$8,396	$27,987	$23,340	$4,646
1.0				SC Configuration Option	$376,972	$86,993	$289,978	$72,041	$216,556
	1.01			Preliminary & Final Design	$77,134	$17,800	$59,334	$39,281	$18,672
	1.02			Linac Structures	$106,906	$24,671	$82,236	$12,953	$69,282
	1.03			RF Power	$124,657	$28,767	$95,890	$5,763	$90,128
	1.04			Cryogenic Supply	$32,524	$7,505	$25,018	$440	$24,578
	1.05			Civil Structures	$15,182	$3,504	$11,678	$0	$11,678
	1.06			Installation & Checkout	$20,568	$4,746	$15,822	$13,605	$2,217

					Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry)								Purchased Material & Services ($k)		
WBS Level					Los Alamos		Prime Contractor			Subcontractor					
1	2	3	4	Name	TSM	TEC	TSM	TEC	Craft	TSM	TEC	Craft	Raw Material	Equipment	Services
1.0				NC Configuration Option	33.74	1.06	227.94	268.33	0.00	27.28	146.47	52.56	$111,842	$67,844	$8,113
	1.01			Preliminary & Final Design	15.50	0.00	120.79	92.00	0.00	0.00	0.00	0.00	$5,275	$12,602	$743
	1.02			Linac Structures	10.21	1.06	22.00	65.33	0.00	26.29	146.03	0.00	$5,055	$34,552	$0
	1.03			RF Power	3.00	0.00	33.00	33.00	0.00	0.00	0.00	0.00	$101,513	$1,984	$0
	1.04			Thermal Control System	1.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	$0	$8,624	$0
	1.05			Civil Structures	0.00	0.00	0.15	0.00	0.00	0.00	0.00	1.00	$0	$6,342	$6,465
	1.06			Installation & Checkout	4.02	0.00	49.00	78.00	0.00	1.00	0.44	51.56	$0	$3,741	$905
1.0				SC Configuration Option	49.86	0.57	177.67	200.47	0.00	5.59	11.89	10.55	$96,050	$79,488	$39,730
	1.01			Preliminary & Final Design	36.00	0.00	109.89	82.70	0.00	0.00	0.00	0.00	$5,923	$12,243	$838
	1.02			Linac Structures	5.66	0.57	24.51	37.96	0.00	5.59	11.89	1.50	$0	$41,471	$27,811
	1.03			RF Power	2.00	0.00	16.50	16.50	0.00	0.00	0.00	0.00	$90,128	$0	$0
	1.04			Cryogenic Supply	2.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0	$24,578	$0
	1.05			Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0	$0	$11,081
	1.06			Installation & Checkout	4.00	0.00	26.77	63.32	0.00	0.00	0.00	9.05	$0	$1,196	$0

Cost Comparison by Level 2 WBS

Cost without Contingency



Cost Metrics - Top Level

Cost without Contingency

Combined Costs (1.02, 1.03, 1.04, 1.05, 1.06)	Overall Cost - ($k)	Overall Length (m)	($k/m)	Energy In (MeV)	Energy Out (MeV)	Energy Gain (MeV)	(MeV/m)	($/eV)
Normal Conducting Linac	$246,083	180.20	$1,366	6.70	210.00	203.3	1.13	$1.210
Superconducting Linac	$230,644	205.25	$1,124	6.70	211.00	204.3	1.00	$1.129

Cost Excluding Preliminary & Final Design

Cost Metrics - Details

Cost without Contingency

1.02 Linac Structure Costs	Overall Cost - ($k)	Overall Length (m)	($k/m)	Energy In (MeV)	Energy Out (MeV)	Energy Gain (MeV)	(MeV/m)	($/eV)	Section Avg ($/eV)
CCDTL	$41,954	94.05	$446.08	6.70	97.61	90.91	0.97	$0.461	$0.461
CCL	$38,896	86.15	$451.50	97.61	210.00	112.39	1.30	$0.346	$0.346
Section 1: 350 MHz βg=0.175 (32 cavities)**	$15,716	36.21	$434.02	6.70	14.17	7.47	0.21	$2.104	
Section 2: 350 MHz βg=0.200 (48 cavities)	$21,972	48.82	$450.06	14.17	43.54	29.374	0.60	$0.748	$0.564
Section 3: 350 MHz βg=0.340 (48 cavities)	$23,816	55.39	$429.98	43.54	109.04	65.496	1.18	$0.364	
Section 4: 700 MHz βg=0.480 (40 cavities)	$20,732	64.83	$319.79	109.04	211.00	101.96	1.57	$0.203	$0.203

** Includes cost for Matching Section

1.03 RF System Costs	Overall Cost - ($k)	Installed Power (MW)	($/W)	Section Avg ($/W)	Energy Gain (MeV)	($/eV)	Section Avg ($/eV)
CCDTL	$48,184	18.5	$2.60	$2.60	90.91	$0.530	$0.530
CCL	$66,638	25.5	$2.61	$2.61	112.39	$0.593	$0.593
Section 1: 350 MHz βg=0.175 (32+2 cavities)**	$23,209	0.34	$68.26		7.47	$3.107	
Section 2: 350 MHz βg=0.200 (48 cavities)	$19,244	1.32	$14.58	$20.70	29.374	$0.655	$0.603
Section 3: 350 MHz βg=0.340 (48 cavities)	$19,244	1.32	$14.58		65.496	$0.294	
Section 4: 700 MHz βg=0.480 (40 cavities)	$34,194	2.00	$17.10	$17.10	101.96	$0.335	$0.335

** Includes Matching Section Supplies

1.04 Thermal Control Costs	Overall Cost - ($k)
NC: Thermal Control System	$9,514
SC: Cryogenic Supply	$25,018

1.06 Installation Costs	Overall Cost - ($k)	Overall Length (m)	($k/m)	Energy In (MeV)	Energy Out (MeV)	Energy Gain (MeV)	($/eV)
Normal Conducting Linac	$27,987	180.20	$155.31	6.70	210.00	203.30	$0.138
Superconducting Linac	$15,822	205.25	$77.08	6.70	211.00	204.30	$0.077

Preliminary & Final Design Comparison - I

WBS Level								Subtotals	
1	2	3	4	Name	TOTAL with contingency ($k)	Contingency ($k)	Total w/o cont($k)	Labor ($k)	M&S ($k)
1.0				**NC Configuration Option**					
	1.01			**Preliminary & Final Design**	**$75,714**	**$17,473**	**$58,242**	$38,221.70	$18,150.84
		1.01.01		**Linac Structures**			**$31,662**	**$22,766.70**	**$7,026.41**
			1.01.01.01	Design of CCDTL			$5,608	$4,200.00	$1,407.60
			1.01.01.02	Design of CCL			$5,352	$4,000.00	$1,352.40
			1.01.01.03	Design of Magnets			$1,869	$1,400.00	$469.20
			1.01.01.04	Design of Diagnostics			$10,689	$8,326.70	$2,362.01
			1.01.01.05	Design of Vacuum Systems			$1,869	$1,400.00	$469.20
			1.01.01.06	Design of Support & Align Systems			$1,869	$1,400.00	$469.20
			1.01.01.07	Design of EPICS Control System			$1,869	$1,400.00	$469.20
			1.01.01.08	Physics Support			$2,537	$2,040.00	$496.80
		1.01.02		**RF Power**			**$22,225**	**$12,755.00**	**$9,470.20**
			1.01.02.01	Design of HV			$6,860	$3,810.00	$3,049.80
			1.01.02.02	Design of HPRF			$7,526	$4,730.00	$2,795.60
			1.01.02.03	Design of LLRF			$7,840	$4,215.00	$3,624.80
		1.01.03		**Thermal Control System**			**$3,611**	**$2,700.00**	**$910.80**
			1.01.03.01	Design of Thermal Control System			$3,611	$2,700.00	$910.80
		1.01.04		**Civil Structures**			**$743**	**$0.00**	**$743.43**
			1.01.04.01	Design of Civil Structures			$743	$0.00	$743.43
1.0				**SC Configuration Option**					
	1.01			**Preliminary & Final Design**	**$77,134**	**$17,800**	**$59,334**	$39,280.56	$18,672.35
		1.01.01		**Linac Structures**			**$34,499**	**$25,346.06**	**$7,771.46**
			1.01.01.01	Design of Matching Section			$2,868	$2,150.00	$717.60
			1.01.01.02	Design of Spoke Cavities			$6,246	$4,700.00	$1,545.60
			1.01.01.03	Design of Elliptical Cavities			$1,952	$1,510.00	$441.60
			1.01.01.04	Design of Couplers			$1,381	$1,050.00	$331.20
			1.01.01.05	Design of Magnets			$1,381	$1,050.00	$331.20
			1.01.01.06	Design of Diagnostics			$10,883	$8,466.06	$2,417.06
			1.01.01.07	Design of Cryostats			$5,105	$3,780.00	$1,324.80
			1.01.01.08	Design of Vacuum Systems			$691	$525.00	$165.60
			1.01.01.09	Design of Support & Align Systems			$691	$525.00	$165.60
			1.01.01.10	Design of EPICS Control System			$0	$0.00	$0.00
			1.01.01.011	Physics Support			$3,302	$2,640.00	$662.40
		1.01.02		**RF Power**			**$22,588**	**$12,525.00**	**$10,062.50**
			1.01.02.01	Design of HV			$6,227.30	$3,810.00	$2,417.30
			1.01.02.02	Design of HPRF			$8,520.40	$4,500.00	$4,020.40
			1.01.02.03	Design of LLRF			$7,839.80	$4,215.00	$3,624.80
		1.01.03		**Cryogenic Supply System**			**$1,409.50**	**$1,409.50**	**$0.00**
		1.01.04		**Civil Structures**			**$838**	**$0.00**	**$838.39**
			1.01.04.01	Design of Civil Structures			$838	$0.00	$838.39

Preliminary & Final Design Comparison - II

WBS Level				Name	Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry)								Purchased Material & Services ($k)		
					Los Alamos		Prime Contractor			Subcontractor					
1	2	3	4		TSM	TEC	TSM	TEC	Craft	TSM	TEC	Craft	Raw Material	Equipment	Services
1.0				**NC Configuration Option**											
	1.01			Preliminary & Final Design	15.50	0.00	120.79	92.00	0.00	0.00	0.00	0.00	$5,275.00	$12,601.61	$743.43
		1.01.01		Linac Structures	6.00	0.00	78.79	51.00	0.00	0.00	0.00	0.00	$0.00	$7,495.61	$0.00
			1.01.01.01	Design of CCDTL	1.50	0.00	12.00	12.00	0.00	0.00	0.00	0.00	$0.00	$1,407.60	$0.00
			1.01.01.02	Design of CCL	0.50	0.00	12.00	12.00	0.00	0.00	0.00	0.00	$0.00	$1,352.40	$0.00
			1.01.01.03	Design of Magnets	0.50	0.00	4.00	4.00	0.00	0.00	0.00	0.00	$0.00	$469.20	$0.00
			1.01.01.04	Design of Diagnostics	1.00	0.00	30.79	11.00	0.00	0.00	0.00	0.00	$0.00	$2,362.01	$0.00
			1.01.01.05	Design of Vacuum Systems	0.50	0.00	4.00	4.00	0.00	0.00	0.00	0.00	$0.00	$469.20	$0.00
			1.01.01.06	Design of Support & Align Systems	0.50	0.00	4.00	4.00	0.00	0.00	0.00	0.00	$0.00	$469.20	$0.00
			1.01.01.07	Design of EPICS Control System	0.50	0.00	4.00	4.00	0.00	0.00	0.00	0.00	$0.00	$469.20	$0.00
			1.01.01.08	Physics Support	1.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00	$0.00	$496.80	$0.00
		1.01.02		RF Power	9.00	0.00	34.00	33.00	0.00	0.00	0.00	0.00	$5,275.00	$4,195.20	$0.00
			1.01.02.01	Design of HV	3.00	0.00	9.00	12.00	0.00	0.00	0.00	0.00	$1,725.00	$1,324.80	$0.00
			1.01.02.02	Design of HPRF	3.00	0.00	13.00	12.00	0.00	0.00	0.00	0.00	$1,250.00	$1,545.60	$0.00
			1.01.02.03	Design of LLRF	3.00	0.00	12.00	9.00	0.00	0.00	0.00	0.00	$2,300.00	$1,324.80	$0.00
		1.01.03		Thermal Control System	0.50	0.00	8.00	8.00	0.00	0.00	0.00	0.00	$0.00	$910.80	$0.00
			1.01.03.01	Design of Thermal Control System	0.50	0.00	8.00	8.00	0.00	0.00	0.00	0.00	$0.00	$910.80	$0.00
		1.01.04		Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$743.43
			1.01.04.01	Design of Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$743.43
1.0				**SC Configuration Option**											
	1.01			Preliminary & Final Design	36.00	0.00	109.89	82.70	0.00	0.00	0.00	0.00	$5,922.50	$12,242.66	$838.39
		1.01.01		Linac Structures	25.00	0.00	72.79	49.00	0.00	0.00	0.00	0.00	$0.00	$8,102.66	$0.00
			1.01.01.01	Design of Matching Section	1.00	0.00	6.00	6.00	0.00	0.00	0.00	0.00	$0.00	$717.60	$0.00
			1.01.01.02	Design of Spoke Cavities	4.00	0.00	12.00	12.00	0.00	0.00	0.00	0.00	$0.00	$1,545.60	$0.00
			1.01.01.03	Design of Elliptical Cavities	2.00	0.00	4.00	2.00	0.00	0.00	0.00	0.00	$0.00	$441.60	$0.00
			1.01.01.04	Design of Couplers	2.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	$0.00	$331.20	$0.00
			1.01.01.05	Design of Magnets	2.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	$0.00	$331.20	$0.00
			1.01.01.06	Design of Diagnostics	4.00	0.00	28.79	11.00	0.00	0.00	0.00	0.00	$0.00	$2,417.06	$0.00
			1.01.01.07	Design of Cryostats	4.00	0.00	8.00	12.00	0.00	0.00	0.00	0.00	$0.00	$1,324.80	$0.00
			1.01.01.08	Design of Vacuum Systems	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	$0.00	$165.60	$0.00
			1.01.01.09	Design of Support & Align Systems	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	$0.00	$165.60	$0.00
			1.01.01.10	Design of EPICS Control System	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
			1.01.01.011	Physics Support	4.00	0.00	8.00	0.00	0.00	0.00	0.00	0.00	$0.00	$662.40	$0.00
		1.01.02		RF Power	9.00	0.00	33.00	33.00	0.00	0.00	0.00	0.00	$5,922.50	$4,140.00	$0.00
			1.01.02.01	Design of HV	3.00	0.00	9.00	12.00	0.00	0.00	0.00	0.00	$1,092.50	$1,324.80	$0.00
			1.01.02.02	Design of HPRF	3.00	0.00	12.00	12.00	0.00	0.00	0.00	0.00	$2,530.00	$1,490.40	$0.00
			1.01.02.03	Design of LLRF	3.00	0.00	12.00	9.00	0.00	0.00	0.00	0.00	$2,300.00	$1,324.80	$0.00
		1.01.03		Cryogenic Supply System	2.00	0.00	4.10	0.70	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
		1.01.04		Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$838.39
			1.01.04.01	Design of Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$838.39

NC Linac Structures Level 4

WBS Level 1	2	3	4	Name	TOTAL with contingency ($K)	Contingency ($K)	Total w/o cont($K)	Subtotals: Labor ($K)	Subtotals: M&S ($K)	Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry): Los Alamos TSM	Los Alamos TEC	Prime Contractor TSM	Prime Contractor TEC	Prime Contractor Craft	Subcontractor TSM	Subcontractor TEC	Subcontractor Craft	Purchased Material & Services ($K): Raw Material	Equipment	Services
1.0				NC Configuration Option																
	1.02			Linac Structures	$105,105	$24,255	$80,850	$40,605.99	$40,244.00	10.21	1.06	22.00	65.33	0.00	26.29	146.03	0.00	$5,054.70	$34,852.04	$0.00
		1.02.01		CCDTL			$19,339	$15,614.41	$3,724.11	3.45	0.00	7.54	26.96	0.00	11.13	61.81	0.00	$3,504.46	$0.00	$0.00
			1.02.01.01	Module 1			$4,618	$2,498.42	$2,119.94	0.52	0.00	1.14	4.05	0.00	2.17	12.06	0.00	$2,119.94	$0.00	$0.00
			1.02.01.02	Module 2			$2,677	$2,427.74	$249.62	0.47	0.00	1.03	3.69	0.00	2.17	12.06	0.00	$249.62	$0.00	$0.00
			1.02.01.03	Module 3			$2,284	$2,023.01	$260.99	0.49	0.00	1.07	3.79	0.00	1.64	9.10	0.00	$260.99	$0.00	$0.00
			1.02.01.04	Module 4			$1,825	$1,637.70	$187.61	0.48	0.00	1.05	3.79	0.00	1.17	6.49	0.00	$187.61	$0.00	$0.00
			1.02.01.05	Module 5			$1,199	$1,070.55	$128.60	0.31	0.00	0.68	2.44	0.00	0.77	4.28	0.00	$128.60	$0.00	$0.00
			1.02.01.06	Module 6			$995	$883.12	$112.31	0.25	0.00	0.55	1.99	0.00	0.64	3.56	0.00	$112.31	$0.00	$0.00
			1.02.01.07	Module 7			$1,000	$865.30	$134.80	0.29	0.00	0.64	2.27	0.00	0.55	3.07	0.00	$134.80	$0.00	$0.00
			1.02.01.08	Module 8			$952	$860.16	$91.36	0.19	0.00	0.41	1.48	0.00	0.73	4.06	0.00	$91.36	$0.00	$0.00
			1.02.01.09	Module 9			$939	$829.28	$109.40	0.22	0.00	0.47	1.69	0.00	0.64	3.56	0.00	$109.40	$0.00	$0.00
			1.02.01.10	Module 10			$950	$839.71	$109.83	0.22	0.00	0.49	1.75	0.00	0.64	3.56	0.00	$109.83	$0.00	$0.00
			1.02.01.10	Module 11			$950	$839.71	$109.83	0.22	0.00	0.49	1.75	0.00	0.64	3.56	0.00	$109.83	$0.00	$0.00
			1.02.01.10	Module 12			$950	$839.71	$109.83	0.22	0.00	0.49	1.75	0.00	0.64	3.56	0.00	$109.83	$0.00	$0.00
		1.02.02		CCL			$22,923	$20,955.26	$1,967.85	3.05	0.00	6.65	23.86	0.00	15.16	84.22	0.00	$1,550.24	$0.00	$0.00
			1.02.02.01	Module 13			$1,584	$1,481.69	$102.12	0.25	0.00	0.54	1.95	0.00	1.40	7.75	0.00	$102.12	$0.00	$0.00
			1.02.02.02	Module 14			$1,589	$1,486.43	$102.12	0.25	0.00	0.55	1.97	0.00	1.40	7.75	0.00	$102.12	$0.00	$0.00
			1.02.02.03	Module 15			$1,727	$1,490.82	$236.57	0.25	0.00	0.56	1.99	0.00	1.40	7.75	0.00	$236.57	$0.00	$0.00
			1.02.02.04	Module 16			$1,609	$1,494.84	$114.41	0.26	0.00	0.56	2.02	0.00	1.40	7.75	0.00	$114.41	$0.00	$0.00
			1.02.02.05	Module 17			$1,620	$1,499.23	$120.81	0.26	0.00	0.57	2.05	0.00	1.40	7.75	0.00	$120.81	$0.00	$0.00
			1.02.02.06	Module 18			$1,312	$1,203.99	$108.38	0.23	0.00	0.49	1.77	0.00	1.09	6.05	0.00	$108.38	$0.00	$0.00
			1.02.02.07	Module 19			$1,316	$1,207.45	$108.40	0.23	0.00	0.50	1.79	0.00	1.09	6.05	0.00	$108.40	$0.00	$0.00
			1.02.02.08	Module 20			$1,321	$1,207.40	$114.03	0.23	0.00	0.50	1.79	0.00	1.09	6.05	0.00	$114.03	$0.00	$0.00
			1.02.02.09	Module 21			$1,250	$1,135.17	$114.83	0.24	0.00	0.52	1.86	0.00	0.98	5.46	0.00	$114.83	$0.00	$0.00
			1.02.02.10	Module 22			$1,257	$1,137.64	$119.85	0.24	0.00	0.52	1.88	0.00	0.98	5.46	0.00	$119.85	$0.00	$0.00
			1.02.02.11	Module 23			$1,183	$1,083.54	$99.91	0.20	0.00	0.44	1.58	0.00	0.98	5.46	0.00	$99.91	$0.00	$0.00
			1.02.02.12	Module 24			$1,190	$1,086.09	$104.40	0.20	0.00	0.45	1.60	0.00	0.98	5.46	0.00	$104.40	$0.00	$0.00
			1.02.02.13	Module 25			$1,193	$1,088.20	$104.40	0.21	0.00	0.45	1.61	0.00	0.98	5.46	0.00	$104.40	$0.00	$0.00
			1.02.02.13	Module 26			$1,193	$1,088.20	$104.40	0.21	0.00	0.45	1.61	0.00	0.98	5.46	0.00	$104.40	$0.00	$0.00
			1.02.02.13	Module 27			$1,193	$1,088.20	$104.40	0.21	0.00	0.45	1.61	0.00	0.98	5.46	0.00	$104.40	$0.00	$0.00
			1.02.02.13	Module 28			$1,193	$1,088.20	$104.40	0.21	0.00	0.45	1.61	0.00	0.98	5.46	0.00	$104.40	$0.00	$0.00
			1.02.02.13	Module 29			$1,193	$1,088.20	$104.40	0.21	0.00	0.45	1.61	0.00	0.98	5.46	0.00	$104.40	$0.00	$0.00
		1.02.03		Focusing Magnets			$12,487	$579.99	$11,907.10	0.41	0.00	0.82	3.27	0.00	0.00	0.00	0.00	$0.00	$11,907.10	$0.00
			1.02.03.01	CCDTL			$8,611	$268.59	$8,342.10	0.19	0.00	0.38	1.51	0.00	0.00	0.00	0.00	$0.00	$8,342.10	$0.00
			1.02.03.02	CCL			$3,876	$311.40	$3,565.00	0.22	0.00	0.44	1.75	0.00	0.00	0.00	0.00	$0.00	$3,565.00	$0.00
		1.02.04		Diagnostics			$7,067	$2,333.94	$4,733.01	2.43	1.06	5.45	5.04	0.00	0.00	0.00	0.00	$0.00	$4,733.01	$0.00
		1.02.05		Vacuum Systems			$16,356	$811.98	$15,544.51	0.57	0.00	1.14	4.57	0.00	0.00	0.00	0.00	$0.00	$15,544.51	$0.00
			1.02.05.01	CCDTL			$8,487	$376.02	$8,110.74	0.26	0.00	0.53	2.12	0.00	0.00	0.00	0.00	$0.00	$8,110.74	$0.00
			1.02.05.02	CCL			$7,870	$435.96	$7,433.77	0.31	0.00	0.61	2.45	0.00	0.00	0.00	0.00	$0.00	$7,433.77	$0.00
		1.02.06		Structural Support & Alignment			$2,678	$310.42	$2,367.41	0.31	0.00	0.41	1.63	0.00	0.00	0.00	0.00	$0.00	$2,367.41	$0.00
			1.02.06.01	CCDTL			$1,379	$143.75	$1,235.26	0.14	0.00	0.19	0.76	0.00	0.00	0.00	0.00	$0.00	$1,235.26	$0.00
			1.02.06.02	CCL			$1,299	$166.67	$1,132.15	0.16	0.00	0.22	0.88	0.00	0.00	0.00	0.00	$0.00	$1,132.15	$0.00

SC Linac Structures Level 4

WBS Level								Subtotals		Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry)								Purchased Material & Services ($K)		
										Los Alamos		Prime Contractor			Subcontractor					
1	2	3	4	Name	TOTAL with contingency ($K)	Contingency ($K)	Total w/o cont($K)	Labor ($K)	M&S ($K)	TSM	TEC	TSM	TEC	Craft	TSM	TEC	Craft	Raw Material	Equipment	Services
1.0				SC Configuration Option																
	1.02			Linac Structures	$106,906	$24,671	$82,236	$12,953.28	$59,282.43	5.66	0.57	24.51	37.96	0.00	5.59	11.89	1.50	$0.00	$41,471.37	$27,811.05
		1.02.01		Matching Section			$524	$0.00	$524.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$524.35	$0.00
			1.02.01.01	Cavities (2) and Beam Tubes			$246	$0.00	$246.10										$246.10	
			1.02.01.02	Magnets (4)			$92	$0.00	$92.00										$92.00	
			1.02.01.03	Magnet Power Supplies (4)			$51	$0.00	$50.60										$50.60	
			1.02.01.04	Vacuum Systems			$51	$0.00	$50.90										$50.90	
			1.02.01.05	Steering magnets & power supplies			$17	$0.00	$17.25										$17.25	
			1.02.01.06	Structural Support & Alignment System			$58	$0.00	$57.50										$57.50	
		1.02.02		Spoke Cavities			$29,459	$1,648.10	$27,811.05	0.99	0.00	4.03	0.00	0.00	0.81	3.32	0.00	$0.00	$0.00	$27,811.05
			1.02.02.01	Section 1: 350 MHz βg=0.175 (32 cavities)			$7,311	$491.46	$6,819.84	0.33	0.00	1.26	0.00	0.00	0.21	0.84	0.00	$0.00	$0.00	$6,819.84
			1.02.02.02	Section 2: 350 MHz βg=0.200 (48 cavities)			$10,644	$579.37	$10,064.71	0.33	0.00	1.39	0.00	0.00	0.30	1.24	0.00	$0.00	$0.00	$10,064.71
			1.02.02.03	Section 3: 350 MHz βg=0.340 (48 cavities)			$11,504	$577.28	$10,926.50	0.33	0.00	1.38	0.00	0.00	0.30	1.23	0.00	$0.00	$0.00	$10,926.50
		1.02.03		Elliptical Cavities			$8,347	$849.66	$7,497.81	0.99	0.00	1.22	3.91	0.00	0.00	0.00	0.00	$0.00	$7,497.81	$0.00
			1.02.03.01	Section 4: 700 MHz β=0.480 (40 cavities)			$8,347	$849.66	$7,497.81	0.99	0.00	1.22	3.91	0.00	0.00	0.00	0.00	$0.00	$7,497.81	$0.00
		1.02.04		Couplers			$20,321	$4,254.20	$16,066.79	1.00	0.00	7.53	3.49	0.00	4.78	8.57	1.50	$0.00	$16,066.79	$0.00
			1.02.04.01	Spoke Cavity Section			$15,998	$2,471.92	$13,525.94	0.50	0.00	5.35	2.91	0.00	2.28	3.45	0.50	$0.00	$13,525.94	$0.00
			1.02.04.02	Elliptical Cavity Section			$4,323	$1,782.28	$2,540.85	0.50	0.00	2.18	0.58	0.00	2.50	5.12	1.00	$0.00	$2,540.85	$0.00
		1.02.05		Focusing Magnets			$2,346	$0.00	$2,346.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$2,346.00	$0.00
			1.02.05.01	Spoke Cavity Section			$1,656	$0.00	$1,656.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$1,656.00	$0.00
			1.02.05.02	Elliptical Cavity Section			$690	$0.00	$690.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$690.00	$0.00
		1.02.06		Diagnostics			$5,035	$1,807.23	$3,228.22	1.68	0.57	4.57	3.74	0.00	0.00	0.00	0.00	$0.00	$3,228.22	$0.00
		1.02.07		Cryostat			$16,202	$4,394.08	$11,808.20	1.00	0.00	7.16	26.81	0.00	0.00	0.00	0.00	$0.00	$11,808.20	$0.00
			1.02.07.01	Spoke Cavity Type			$11,349	$3,013.62	$8,335.20	0.50	0.00	4.93	18.72	0.00	0.00	0.00	0.00	$0.00	$8,335.20	$0.00
			1.02.07.02	Elliptical Cavity Type			$4,853	$1,380.47	$3,473.00	0.50	0.00	2.22	8.09	0.00	0.00	0.00	0.00	$0.00	$3,473.00	$0.00

RF Power Comparison - I

WBS Level								Subtotals	
1	2	3	4	Name	TOTAL with contingency ($k)	Contingency ($k)	Total w/o cont($k)	Labor ($k)	M&S ($k)
1.0				**NC Configuration Option**					
	1.03			**RF Power**	**$149,268**	**$34,446**	**$114,822**	$11,325.00	$103,496.55
		1.03.01		**700 MHZ System**			**$114,822**	**$11,325.00**	**$103,496.55**
			1.03.01.01	1 MW, 700 MHz klystrons, 44 each			$24,283	$3,410.00	$20,872.50
			1.03.01.02	1 MW, 700 MHz circulators, 44 each			$11,144	$4,100.00	$7,043.75
			1.03.01.03	0.5 MW windows, 58 each			$7,116	$3,815.00	$3,300.50
			1.03.01.04	waveguide runs, nominally 2 runs per cavity			$4,002	$0.00	$4,002.00
			1.03.01.05	RF loads, 1 per circulator plus1 per pair of cavities for switch			$2,935	$0.00	$2,934.80
			1.03.01.06	transmitter, 1 per klystron			$20,240	$0.00	$20,240.00
			1.03.01.07	HV system, 1 per klystron			$37,950	$0.00	$37,950.00
			1.03.01.08	LLRF system, 1 per klystron			$4,554	$0.00	$4,554.00
			1.03.01.09	RF infrastructure, shielding, etc,			$1,265	$0.00	$1,265.00
			1.03.01.10	High power switches			$1,334	$0.00	$1,334.00
1.0				**SC Configuration Option**					
	1.03			**RF Power**	**$124,657**	**$28,767**	**$95,890**	$5,762.50	$90,127.80
		1.03.01		**350 & 700 MHZ System**			**$95,890**	**$5,762.50**	**$90,127.80**
			1.03.01.01	10 kW, 350 MHz RF systems, sections 1 (32+2 = 34 each)			$13,847.80	$1,805.00	$12,042.80
			1.03.01.02	10 kW, 350 MHz circulators, 34 each			$2,536.50	$1,950.00	$586.50
			1.03.01.03	10 kW window/couplers, 1 per cavity, 34 each			$2,589.50	$1,807.50	$782.00
			1.03.01.04	55 kW, 350 MHz RF systems, sections 2,3, (48 each)			$20,424.00	$0.00	$20,424.00
			1.03.01.05	55 kW, 350 MHz circulators, 48 each			$1,104.00	$0.00	$1,104.00
			1.03.01.06	30 kW window/couplers, 1 per cavity, 96 each			$3,312.00	$0.00	$3,312.00
			1.03.01.07	waveguide runs, 1 run per cavity			$8,970.00	$0.00	$8,970.00
			1.03.01.08	RF loads, 1 per circulator, 1 per splitter			$897.00	$0.00	$897.00
			1.03.01.09	transmitter, included in RF system			$0.00	$0.00	$0.00
			1.03.01.10	HV, included in RF system			$0.00	$0.00	$0.00
			1.03.01.11	LLRF system, 1 per RF system			$7,072.50	$0.00	$7,072.50
			1.03.01.12	RF infrastructure, shielding, etc,			$943.00	$0.00	$943.00
			1.03.01.13	100 kW, 700 MHz klystrons, section 4, 20 each			$4,600.00	$0.00	$4,600.00
			1.03.01.14	100 kW, 700 MHz circulators, 20 each			$920.00	$0.00	$920.00
			1.03.01.15	100kW windows, 40 each			$1,610.00	$0.00	$1,610.00
			1.03.01.16	waveguide, 1 run per cavity			$2,760.00	$0.00	$2,760.00
			1.03.01.17	RF loads, 1 per circulator plus1 per splitter			$368.00	$0.00	$368.00
			1.03.01.18	transmitter, 1 per klystron			$11,040.00	$0.00	$11,040.00
			1.03.01.19	HV system, 1 per klystron			$9,200.00	$0.00	$9,200.00
			1.03.01.20	LLRF system, 1 per klystron			$2,960.00	$200.00	$2,760.00
			1.03.01.21	RF infrastructure, shielding, etc,			$736.00	$0.00	$736.00

Note: In SC Configuration WBS 1.03.01.01, .02, .03, .07, .08, .11, and .12 Includes Quantities for Matching Section

RF Power Comparison - II

WBS Level				Name	Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry)								Purchased Material & Services ($k)		
					Los Alamos		Prime Contractor			Subcontractor					
1	2	3	4	Name	TSM	TEC	TSM	TEC	Craft	TSM	TEC	Craft	Raw Material	Equipment	Services
1.0				NC Configuration Option											
	1.03			RF Power	3.00	0.00	33.00	33.00	0.00	0.00	0.00	0.00	$101,512.80	$1,983.75	$0.00
		1.03.01		700 MHZ System	3.00	0.00	33.00	33.00	0.00	0.00	0.00	0.00	$101,512.80	$1,983.75	$0.00
			1.03.01.01	1 MW, 700 MHz klystrons, 44 each	1.00	0.00	9.00	12.00	0.00	0.00	0.00	0.00	$20,240.00	$632.50	$0.00
			1.03.01.02	1 MW, 700 MHz circulators, 44 each	1.00	0.00	12.00	12.00	0.00	0.00	0.00	0.00	$6,325.00	$718.75	$0.00
			1.03.01.03	0.5 MW windows, 58 each	1.00	0.00	12.00	9.00	0.00	0.00	0.00	0.00	$2,668.00	$632.50	$0.00
			1.03.01.04	waveguide runs, nominally 2 runs per cavity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$4,002.00	$0.00	$0.00
			1.03.01.05	RF loads, 1 per circulator plus1 per pair of cavities for switch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$2,934.80	$0.00	$0.00
			1.03.01.06	transmitter, 1 per klystron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$20,240.00	$0.00	$0.00
			1.03.01.07	HV system, 1 per klystron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$37,950.00	$0.00	$0.00
			1.03.01.08	LLRF system , 1 per klystron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$4,554.00	$0.00	$0.00
			1.03.01.09	RF infrastructure, shielding, etc,	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$1,265.00	$0.00	$0.00
			1.03.01.10	High power switches	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$1,334.00	$0.00	$0.00
1.0				SC Configuration Option											
	1.03			RF Power	2.00	0.00	16.50	16.50	0.00	0.00	0.00	0.00	$90,127.80	$0.00	$0.00
		1.03.01		350 & 700 MHZ System	2.00	0.00	16.50	16.50	0.00	0.00	0.00	0.00	$90,127.80	$0.00	$0.00
			1.03.01.01	10 kW, 350 MHz RF systems, sections 1 (32+2 = 34 each)	1.00	0.00	4.50	6.00	0.00	0.00	0.00	0.00	$12,042.80	$0.00	$0.00
			1.03.01.02	10 kW, 350 MHz circulators, 34 each	0.00	0.00	6.00	6.00	0.00	0.00	0.00	0.00	$586.50	$0.00	$0.00
			1.03.01.03	10 kW window/couplers, 1 per cavity, 34 each	0.00	0.00	6.00	4.50	0.00	0.00	0.00	0.00	$782.00	$0.00	$0.00
			1.03.01.04	55 kW, 350 MHz RF systems, sections 2,3, (48 each)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$20,424.00	$0.00	$0.00
			1.03.01.05	55 kW, 350 MHz circulators, 48 each	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$1,104.00	$0.00	$0.00
			1.03.01.06	30 kW window/couplers, 1 per cavity, 96 each	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$3,312.00	$0.00	$0.00
			1.03.01.07	waveguide runs, 1 run per cavity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$8,970.00	$0.00	$0.00
			1.03.01.08	RF loads, 1 per circulator, 1 per splitter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$897.00	$0.00	$0.00
			1.03.01.09	transmitter, included in RF system	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
			1.03.01.10	HV, included in RF system	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
			1.03.01.11	LLRF system , 1 per RF system	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$7,072.50	$0.00	$0.00
			1.03.01.12	RF infrastructure, shielding, etc,	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$943.00	$0.00	$0.00
			1.03.01.13	100 kW, 700 MHz klystrons, section 4, 20 each	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$4,600.00	$0.00	$0.00
			1.03.01.14	100 kW, 700 MHz circulators, 20 each	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$920.00	$0.00	$0.00
			1.03.01.15	100kW windows, 40 each	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$1,610.00	$0.00	$0.00
			1.03.01.16	waveguide, 1 run per cavity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$2,760.00	$0.00	$0.00
			1.03.01.17	RF loads, 1 per circulator plus1 per splitter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$368.00	$0.00	$0.00
			1.03.01.18	transmitter, 1 per klystron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$11,040.00	$0.00	$0.00
			1.03.01.19	HV system, 1 per klystron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$9,200.00	$0.00	$0.00
			1.03.01.20	LLRF system , 1 per klystron	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$2,760.00	$0.00	$0.00
			1.03.01.21	RF infrastructure, shielding, etc,	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$736.00	$0.00	$0.00

Thermal Control/Cryoplant Comparison

WBS Level 1	2	3	4	Name	TOTAL with contingency ($k)	Contingency ($k)	Total w/o cont($k)	Subtotals: Labor ($k)	Subtotals: M&S ($k)
1.0				NC Configuration Option					
	1.04			Thermal Control System	$12,368	$2,854	$9,514	$890.00	$8,623.60
		1.04.01		Pumps			$4,148	$890.00	$3,257.81
		1.04.02		Heat Exchangers			$1,725	$0.00	$1,724.72
		1.04.03		Fluid Lines & Connectors			$767	$0.00	$766.54
		1.04.04		Temperature Mixing System			$2,875	$0.00	$2,874.53
1.0				SC Configuration Option					
	1.04			Cryogenic Supply	$32,524	$7,505	$25,018	$440.00	$24,578.10
		1.04.01		Cryoplant Substation & Switchgear			$1,056	$0.00	$1,056.00
		1.04.02		Cold Boxes, Compressor Systems, Storage Systems, Controls			$22,140	$270.00	$21,869.55
		1.04.03		Transfer Lines & Inserts			$1,823	$170.00	$1,652.55

WBS Level					Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry)								Purchased Material & Services ($k)		
					Los Alamos		Prime Contractor			Subcontractor					
1	2	3	4	Name	TSM	TEC	TSM	TEC	Craft	TSM	TEC	Craft	Raw Material	Equipment	Services
1.0				NC Configuration Option											
	1.04			Thermal Control System	1.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	$0.00	$8,623.60	$0.00
		1.04.01		Pumps	1.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	$0.00	$3,257.81	$0.00
		1.04.02		Heat Exchangers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$1,724.72	$0.00
		1.04.03		Fluid Lines & Connectors	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$766.54	$0.00
		1.04.04		Temperature Mixing System	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$2,874.53	$0.00
1.0				SC Configuration Option											
	1.04			Cryogenic Supply	2.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$24,578.10	$0.00
		1.04.01		Cryoplant Substation & Switchgear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$1,056.00	$0.00
		1.04.02		Cold Boxes, Compressor Systems, Storage Systems, Controls	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$21,869.55	$0.00
		1.04.03		Transfer Lines & Inserts	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$1,652.55	$0.00

Civil Structures Comparison

WBS Level							Total w/o cont($k)	Subtotals	
1	2	3	4	Name	TOTAL with contingency ($k)	Contingency ($k)		Labor ($k)	M&S ($k)
1.0				NC Configuration Option					
	1.05			Civil Structures	$16,784	$3,873	$12,911	$104.50	$12,806.65
		1.05.01		Linac Tunnel			$6,465	$0.00	$6,464.65
		1.05.02		Waveguide cooling system			$1,167	$104.50	$1,062.00
		1.05.03		Prime Power			$5,280	$0.00	$5,280.00
1.0				SC Configuration Option					
	1.05			Civil Structures	$15,182	$3,504	$11,678	$0.00	$11,678.35
		1.05.01		Linac Tunnel			$7,290	$0.00	$7,290.35
		1.05.02		Cryoplant Building			$3,790	$0.00	$3,790.40
		1.05.03		Prime Power			$598	$0.00	$597.60

Installation & Checkout Comparison - I

WBS Level								Subtotals	
1	2	3	4	Name	TOTAL with contingency ($k)	Contingency ($k)	Total w/o cont($k)	Labor ($k)	M&S ($k)
1.0				**NC Configuration Option**					
	1.06			**Installation & Checkout**	**$36,382**	**$8,396**	**$27,987**	$23,340.38	$4,646.14
		1.06.01		**Linac Structures**			**$17,364**	**$14,945.00**	**$2,418.59**
			1.06.01.01	Installation & Checkout of CCDTL			$5,077	$4,380.00	$697.19
			1.06.01.02	Installation & Checkout of CCL			$5,077	$4,380.00	$697.19
			1.06.01.03	Installation & Checkout of Magnets			$2,334	$1,985.00	$348.59
			1.06.01.04	Installation & Checkout of Diagnostics			$703	$610.00	$93.44
			1.06.01.05	Installation & Checkout of Vacuum Systems			$2,086	$1,795.00	$291.09
			1.06.01.06	Installation & Checkout of Support & Align Systems			$2,086	$1,795.00	$291.09
			1.06.01.07	Installation & Checkout of EPICS Control System			$0	$0.00	$0.00
		1.06.02		**RF Power**			**$9,043**	**$7,720.00**	**$1,322.50**
			1.06.02.01	HV and HPRF installation			$4,979	$4,260.00	$718.75
			1.06.02.02	LLRF installation			$4,064	$3,460.00	$603.75
		1.06.03		**Resonance Control System**			**$675**	**$675.38**	**$0.00**
		1.06.04		**Civil Structures**			**$905**	**$0.00**	**$905.05**
1.0				**SC Configuration Option**					
	1.06			**Installation & Checkout**	**$20,568**	**$4,746**	**$15,822**	$13,604.92	$2,216.65
		1.06.01		**Linac Structures**			**$7,736**	**$6,540.00**	**$1,196.00**
			1.06.01.01	Installation & Checkout of Matching Section			$266	$230.00	$35.94
			1.06.01.02	Integration, Install & Checkout of Spoke Cavity Cryostat			$2,222	$1,870.00	$352.19
			1.06.01.03	Integration, Install & Checkout of Elliptical Cavity Cryostat			$1,733	$1,450.00	$283.19
			1.06.01.04	Installation & Checkout of Diagnostics			$633	$540.00	$93.44
			1.06.01.05	Installation & Checkout of Vacuum Systems			$2,305	$1,960.00	$345.00
			1.06.01.06	Installation & Checkout of Support & Align Systems			$576	$490.00	$86.25
			1.06.01.07	Installation & Checkout of EPICS Control System			$0	$0.00	$0.00
		1.06.02		**RF Power**			**$6,377**	**$6,376.67**	**$0.00**
			1.06.02.01	HV and HPRF installation			$4,266.67	$4,266.67	$0.00
			1.06.02.02	LLRF installation			$2,110.00	$2,110.00	$0.00
		1.06.03		**Cryogenic Supply**			**$688.25**	**$688.25**	**$0.00**
		1.06.04		**Civil Structures**			**$1,021**	**$0.00**	**$1,020.65**

Installation & Checkout Comparison - II

WBS Level					Labor expressed in FTE-years (1750 Hours LANL, 1824 Hours Industry)								Purchased Material & Services ($k)		
					Los Alamos		Prime Contractor			Subcontractor					
1	2	3	4	Name	TSM	TEC	TSM	TEC	Craft	TSM	TEC	Craft	Raw Material	Equipment	Services
1.0				**NC Configuration Option**											
	1.06			Installation & Checkout	4.02	0.00	49.00	78.00	0.00	1.00	0.44	51.56	$0.00	$3,741.09	$905.05
		1.06.01		Linac Structures	1.13	0.00	33.00	50.00	0.00	0.00	0.00	34.00	$0.00	$2,418.59	$0.00
			1.06.01.01	Installation & Checkout of CCDTL	0.25	0.00	10.00	14.00	0.00	0.00	0.00	10.00	$0.00	$697.19	$0.00
			1.06.01.02	Installation & Checkout of CCL	0.25	0.00	10.00	14.00	0.00	0.00	0.00	10.00	$0.00	$697.19	$0.00
			1.06.01.03	Installation & Checkout of Magnets	0.13	0.00	4.00	8.00	0.00	0.00	0.00	4.00	$0.00	$348.59	$0.00
			1.06.01.04	Installation & Checkout of Diagnostics	0.25	0.00	1.00	2.00	0.00	0.00	0.00	2.00	$0.00	$93.44	$0.00
			1.06.01.05	Installation & Checkout of Vacuum Systems	0.13	0.00	4.00	6.00	0.00	0.00	0.00	4.00	$0.00	$291.09	$0.00
			1.06.01.06	Installation & Checkout of Support & Align Systems	0.13	0.00	4.00	6.00	0.00	0.00	0.00	4.00	$0.00	$291.09	$0.00
			1.06.01.07	Installation & Checkout of EPICS Control System	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
		1.06.02		RF Power	2.00	0.00	16.00	28.00	0.00	0.00	0.00	14.00	$0.00	$1,322.50	$0.00
			1.06.02.01	HV and HPRF installation	1.00	0.00	8.00	16.00	0.00	0.00	0.00	10.00	$0.00	$718.75	$0.00
			1.06.02.02	LLRF installation	1.00	0.00	8.00	12.00	0.00	0.00	0.00	4.00	$0.00	$603.75	$0.00
		1.06.03		Resonance Control System	0.90	0.00	0.00	0.00	0.00	1.00	0.44	3.56	$0.00	$0.00	$0.00
		1.06.04		Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$905.05
1.0				**SC Configuration Option**											
	1.06			Installation & Checkout	4.00	0.00	26.77	63.32	0.00	0.00	0.00	9.05	$0.00	$1,196.00	$1,020.65
		1.06.01		Linac Structures	1.00	0.00	13.70	26.90	0.00	0.00	0.00	9.05	$0.00	$1,196.00	$0.00
			1.06.01.01	Installation & Checkout of Matching Section	0.25	0.00	0.50	0.50	0.00	0.00	0.00	0.25	$0.00	$35.94	$0.00
			1.06.01.02	Integration, Install & Checkout of Spoke Cavity Cryostat	0.25	0.00	4.00	8.00	0.00	0.00	0.00	2.00	$0.00	$352.19	$0.00
			1.06.01.03	Integration, Install & Checkout of Elliptical Cavity Cryostat	0.25	0.00	3.20	6.40	0.00	0.00	0.00	0.80	$0.00	$283.19	$0.00
			1.06.01.04	Installation & Checkout of Diagnostics	0.25	0.00	1.00	2.00	0.00	0.00	0.00	1.00	$0.00	$93.44	$0.00
			1.06.01.05	Installation & Checkout of Vacuum Systems	0.00	0.00	4.00	8.00	0.00	0.00	0.00	4.00	$0.00	$345.00	$0.00
			1.06.01.06	Installation & Checkout of Support & Align Systems	0.00	0.00	1.00	2.00	0.00	0.00	0.00	1.00	$0.00	$86.25	$0.00
			1.06.01.07	Installation & Checkout of EPICS Control System	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
		1.06.02		RF Power	2.00	0.00	11.67	34.67	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
			1.06.02.01	HV and HPRF installation	1.00	0.00	6.67	26.67	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
			1.06.02.02	LLRF installation	1.00	0.00	5.00	8.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
		1.06.03		Cryogenic Supply	1.00	0.00	1.40	1.75	0.00	0.00	0.00	0.00	$0.00	$0.00	$0.00
		1.06.04		Civil Structures	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$0.00	$0.00	$1,020.65

Basis of Estimate Categories *

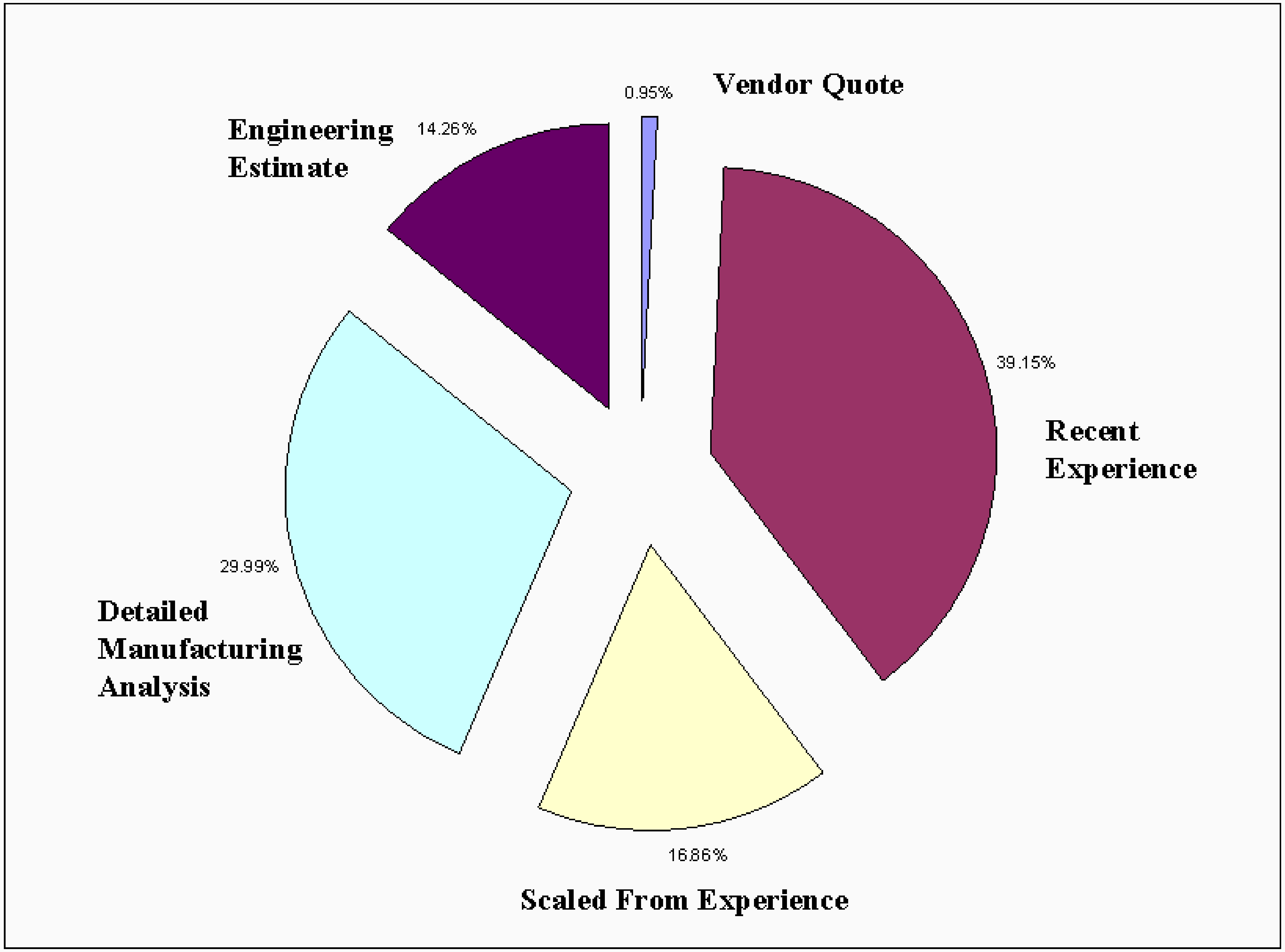
CATEGORY	TITLE	DESCRIPTION
1	Vendor Quote	Recent quotation from a vendor or cost information from supplier price lists.
2	Recent Experience	Actual cost of identical work or procurements.
3	Scaled from Experience	Actual cost of past similar work or procurements scaled to the parameters of the ADTF linac.
4	Detailed Manufacturing Analysis	A detailed cost analysis made from detail drawings and manufacturing flow charts.
5	Engineering Estimate	An estimate to perform work for which we do not have specific experience.

- Category 3 augmented to include data scaled from cost estimates on other similar programs (e.g. APT, SNS, RIA…) **

* Ref: LANSCE-1:01-010, 1/26/01

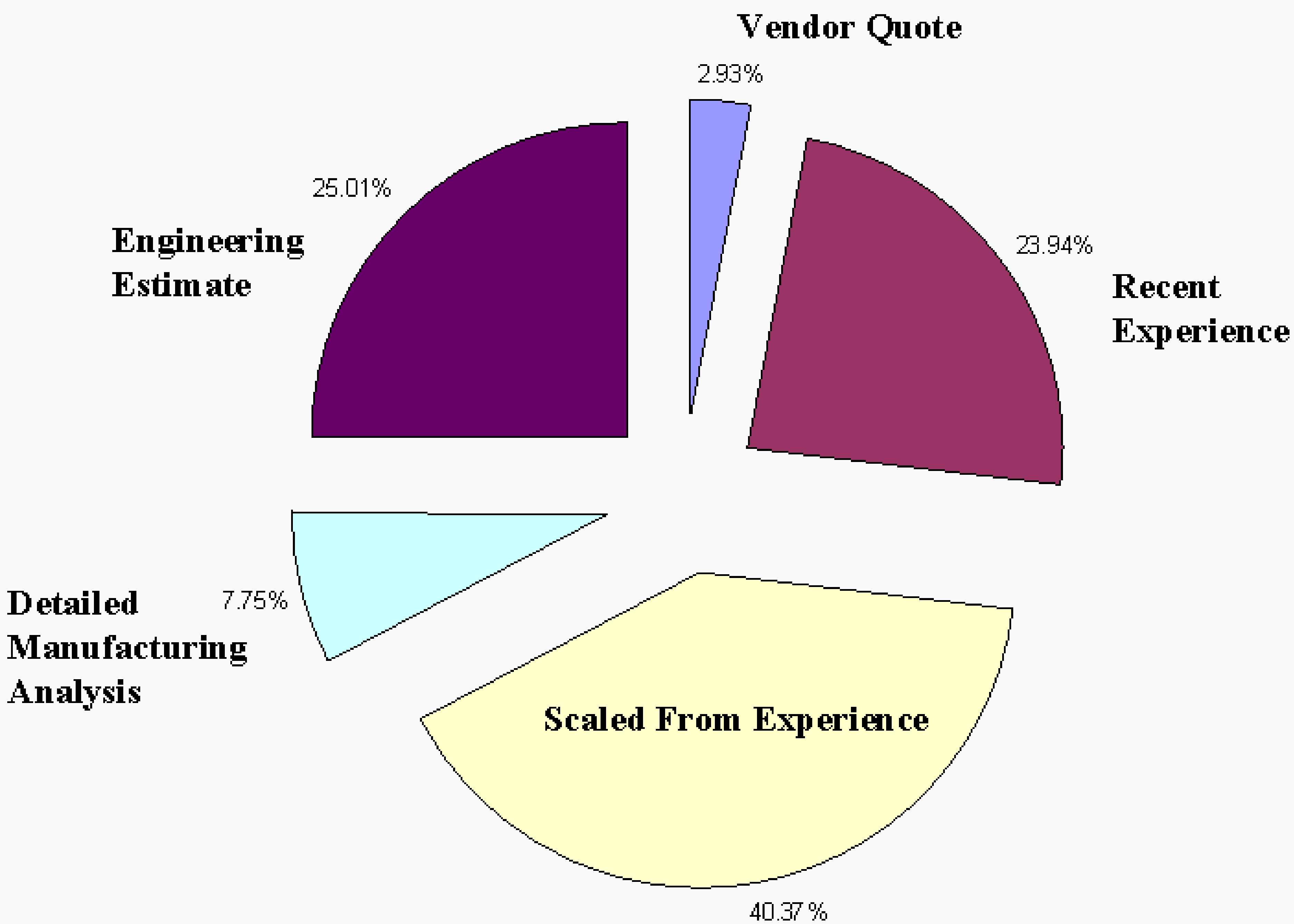
** Phone conversation: J. Rathke & D. Schrage 4/2/01

Basis of Estimate Normal Conducting Estimate



AAA

Basis of Estimate Superconducting Estimate



Summary

- Both options can be built to the schedule supplied
  - configuration specific optimization may yield differences ==> more study required
- The cost of design, fabrication, installation and checkout of the two configurations is with-in the error range of the individual cost estimates ==> system costs are equal
- Lifecycle cost differences may still exist in areas not examined by this study
  - ED&D
  - start-up/commissioning
  - operations
  - D&D

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

β=0.48 Design Status, Cost, and Schedule

Dominic Chan

β=0.48 Section Extends Superconducting RF Linac Advantages With Minimum Increase in Development Cost

- β=0.48 elliptical cavities cover an energy range presently covered by the Coupled Cavity Linac
  - —There is no increase in the types of structures to develop
- β=0.48 technology has already been developed
  - —Designs developed for β=0.64 Section will be used
  - — β=0.48 section will have similar schedule as β=0.64 Section
  - —If spoke-cavity sections exist, we can also consider cryomodule designs with solenoids
- β=0.48 SC Linac has reliability advantages
  - —Reduce probability of beam halo interception with 5-cm aperture radius
  - —Allow operations with component failures

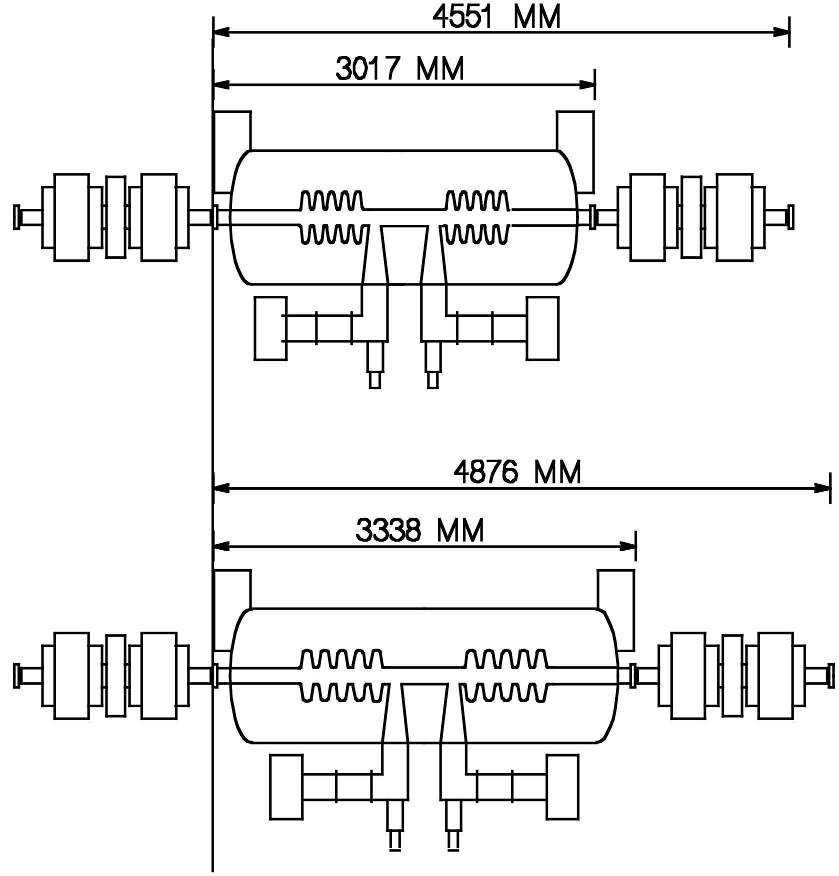
Proposed development costs less than the saving of one-year operating cost and has no impact to ADTF construction schedule

β=0.64 and 0.48 Technologies Are Interchangeable

- Same couplers
- Same tuners
- Scaled helium vessels
- Scaled cryomodules
- Same quadrupole focusing lattice

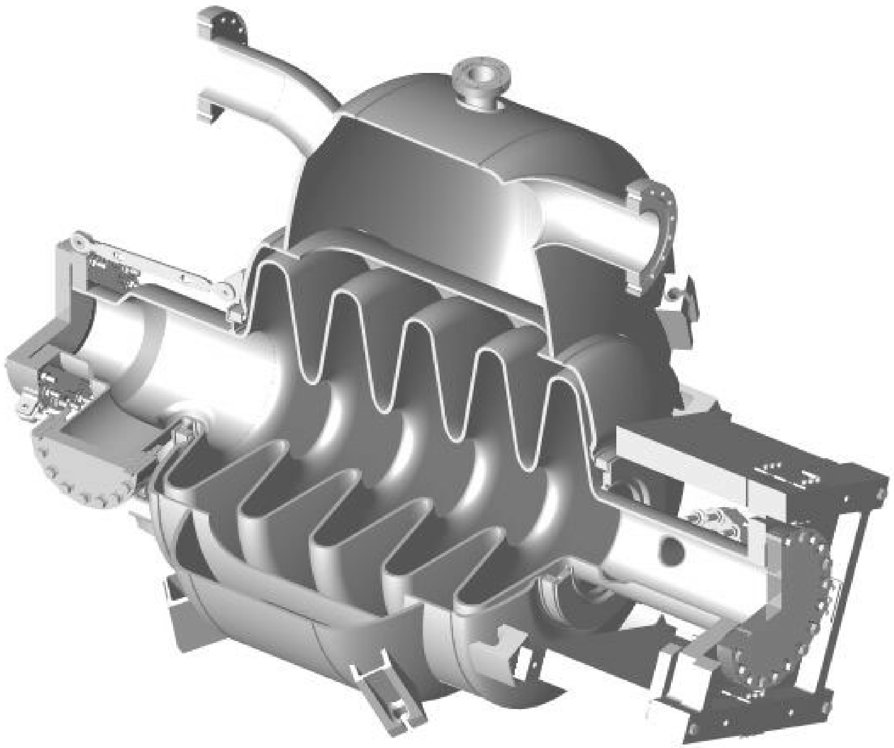
- Shorter niobium cavities
  - —Mechanical stability issue to be addressed

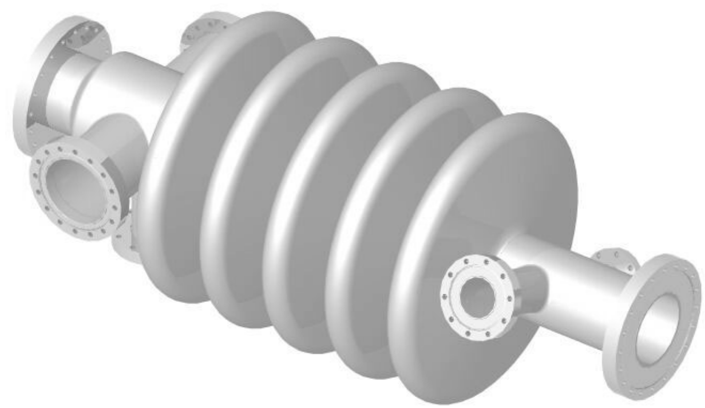
Sample Lattice with 2-Cavity Cryomodule With β=0.64 Technology



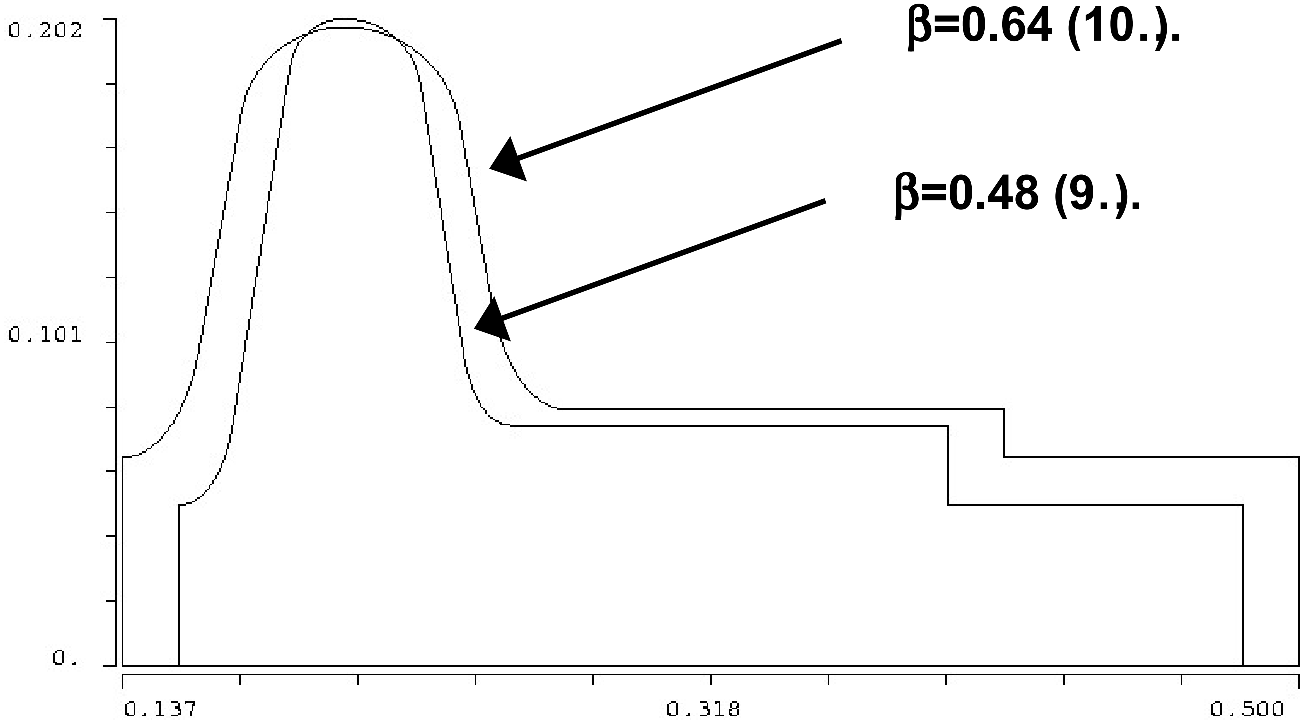
*β=0.48 cavity and coupler requirements are, respectively, 6 MV/m and 300 kW@100mA

Only Differences Will Be in the Niobium Cavities





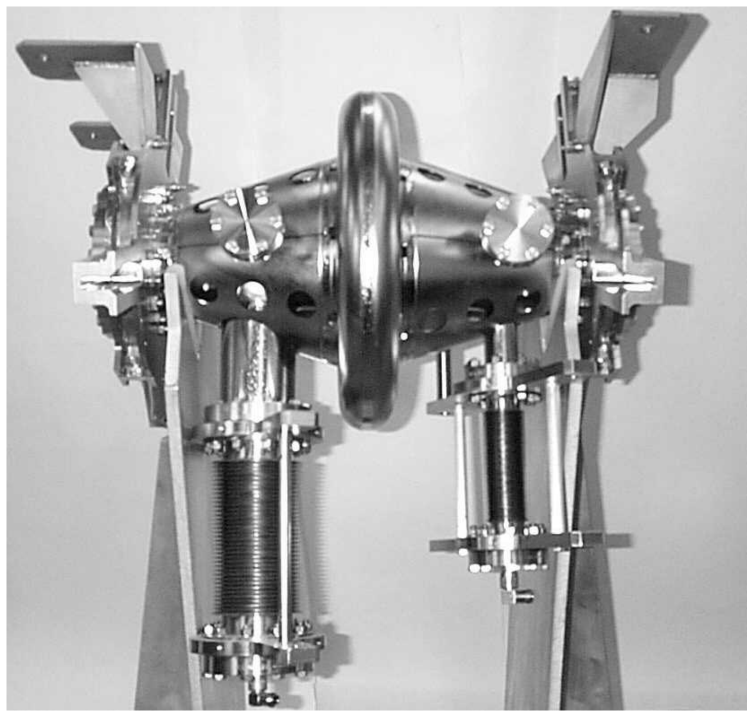
Cell Length of β=0.48 is 75% of That for β=0.64



***Endcell shapes are shown**

We Have Two β=0.48 Single-Cell Cavities Successfully Tested in 1998 Showing No Multipacting

- E_{acc} of 12.3 MV/m achieved; Q-value of 7×10^9@ 6MV/m
- Cavities had 3… wall slopes and used stiffeners
- New design will reduce cost by eliminating stiffeners
  - —Stiffeners were eliminated in β=0.64 cavities by using larger wall slope and wall thickness



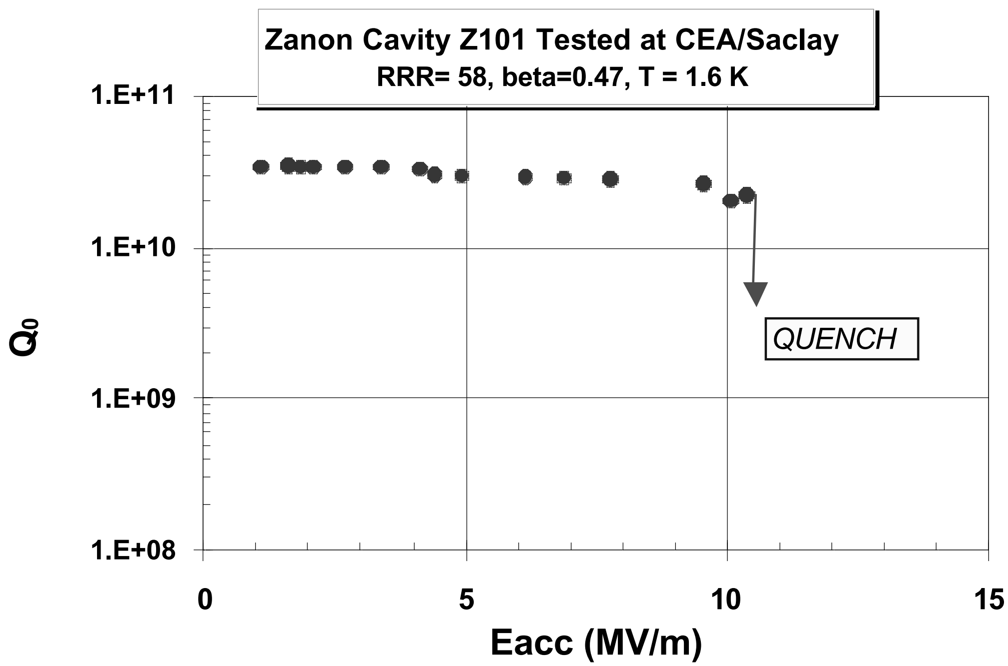
Comparing Parameters of β=0.64 and 0.48 Cavities

	β=0.47 (Saclay)	β=0.48 (ADTF)	β=0.64 (APT)
Frequency (MHz)	704	700	700
Cavity length (m)	0.50	0.51	0.69
E_{pk}/E_a	3.58	3.64	3.38
H_{pk}/E_a (Gauss/(MV/m)	59.0	76.6	70.0
Q_o @16 nΩ	9.54×10^9	8.27×10^9	9.4×10^9
Geometric factor	153	134	149
U (J) @6MV/m	12.7	20.1	22.4
Pcav (W) @6MV/m	5.90	10.50	10.50
ZT^2/Q (Ω)	79.5	107.5	191.0
Cell-to-cell coupling (%)	1.35	1.50	>2.60
Cell wall slope (degrees)	5.0 - 6.0	7.0 - 8.5	10.0
Aperture radius (cm)	4.0	5.0	6.5
Aperture radius (cm) @coupler	6.5	7.5	8.0
Cell wall thickness (mm)	5.0	5.0	4.0
External Q	1.5×10^6 @ 20mA	3.9×10^5@100mA	2.0×10^5@100mA

*Parameters for ADTF β=0.48 cavities are working progress

Saclay/Milano Is Working on β=0.47 5-Cell Cavities Similar to ADTF Requirements

- One single-cell cavity was built with reactor-grade niobium (RRR=58) and tested (see test results below)
- Fabrication of one single-cell cavity with RRR=250 niobium is scheduled to be completed in two months
- Two 5-cell cavities with RRR=250 are scheduled for fabrication this year in Zanon



The Path Towards β=0.48 Section Is A Straight Forward Extension of Our β=0.64 Section Experience

AAA

Core Program

¥ Design cavity with mechanical stability

—Eliminate stiffeners by trading off among parameters including peak surface fields, cell wall slope, and cell wall thickness

—Optimize linac architecture for high real-estate gradient

¥ Build and test two simple β=0.48 5-cell cavities without helium vessels

—Determine performance margins

¥ Design cavities with helium vessels

Optional Program

¥ Build and test two cavities complete with helium vessels

—Demonstrate integrated cavity and coupler performance in β=0.64 cryomodule

Saclay has expressed interest in collaborating with us

AAA

Cost and Schedule Summary

	Core	Optional
FY02	1.9	0.4
FY03	0.8	1.9
FY04	0.0	0.5
Program Total	2.7	2.8

- Cost numbers are in M$, no niobium cost for Core program, no escalation for inflation, fully burdened LANL labor rate, and with 20% contingency
- Work starts in October, 2001

- Core Program will deliver by March, 2003 (1.5 years)
  - Design β=0.48 cavities complete with helium vessels
  - Build and test of two simple cavities w/o helium vessel
- Optional Program will deliver by July 2004 (adding 1.3 years)
  - Build and test three cavities complete with helium vessels

Conclusion

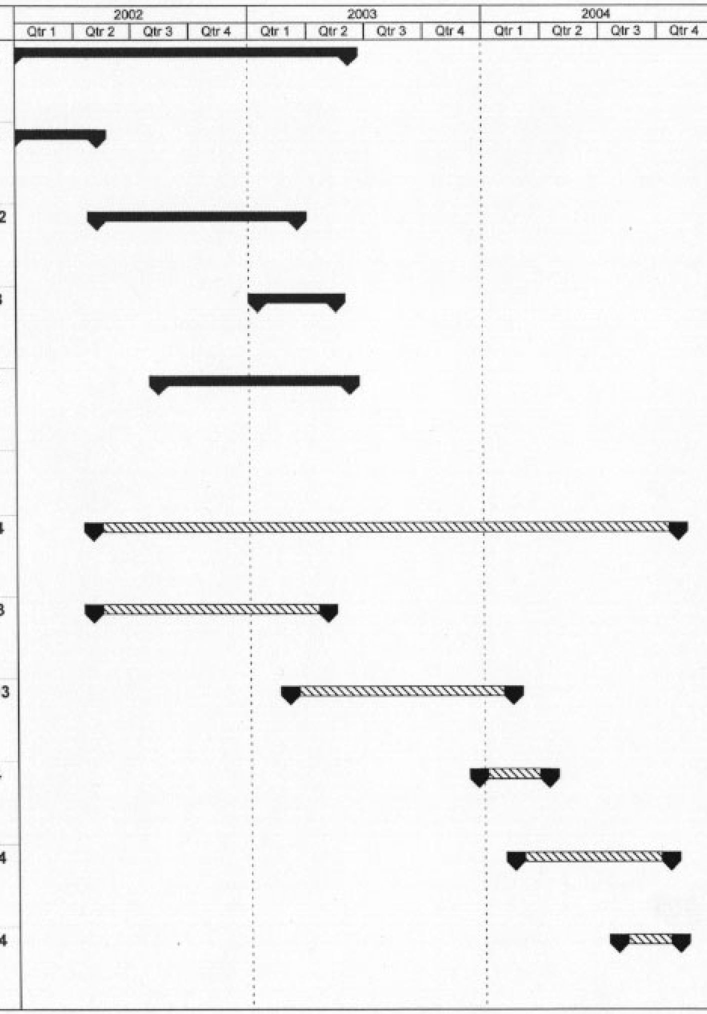
AAA

Based on β=0.64 technology, a SCRF β=0.48 Section can be developed with minimum development work to enhance ADTF linac performance

Top-Level Schedule

β=0.48 CAVITY DESIGN AND FABRICATION SCHEDULE

Activity Description	Duration	Start	Finish
CORE PROGRAM	68 wks	10/1/01	3/7/03
Design a "simple" cavity	17 wks	10/1/01	2/7/02
Bid and Fabricate 2 each "simple" cavities	40 wks	2/7/02	12/16/02
Test "simple" cavites	16 wks	10/16/02	2/14/03
Design a beta=0.48 cavity and helium vessel (complete cavity)	39 wks	5/14/02	3/7/03
OPTIONAL PROGRAM	125 wks	1/31/02	7/30/04
Procure Niobium and Vessel Bellows and Bulkheads	47 wks	1/31/02	1/30/03
Bid & Fabricate 3 each "complete" beta=0.48 cavities	49 wks	12/2/02	11/14/03
Polish, tune, hpr and test each cavity	16 wks	9/22/03	1/9/04
Ship and install helium vessels on cavity	35 wks	11/17/03	7/16/04
Ship cavities back to LANL	14 wks	4/26/04	7/30/04

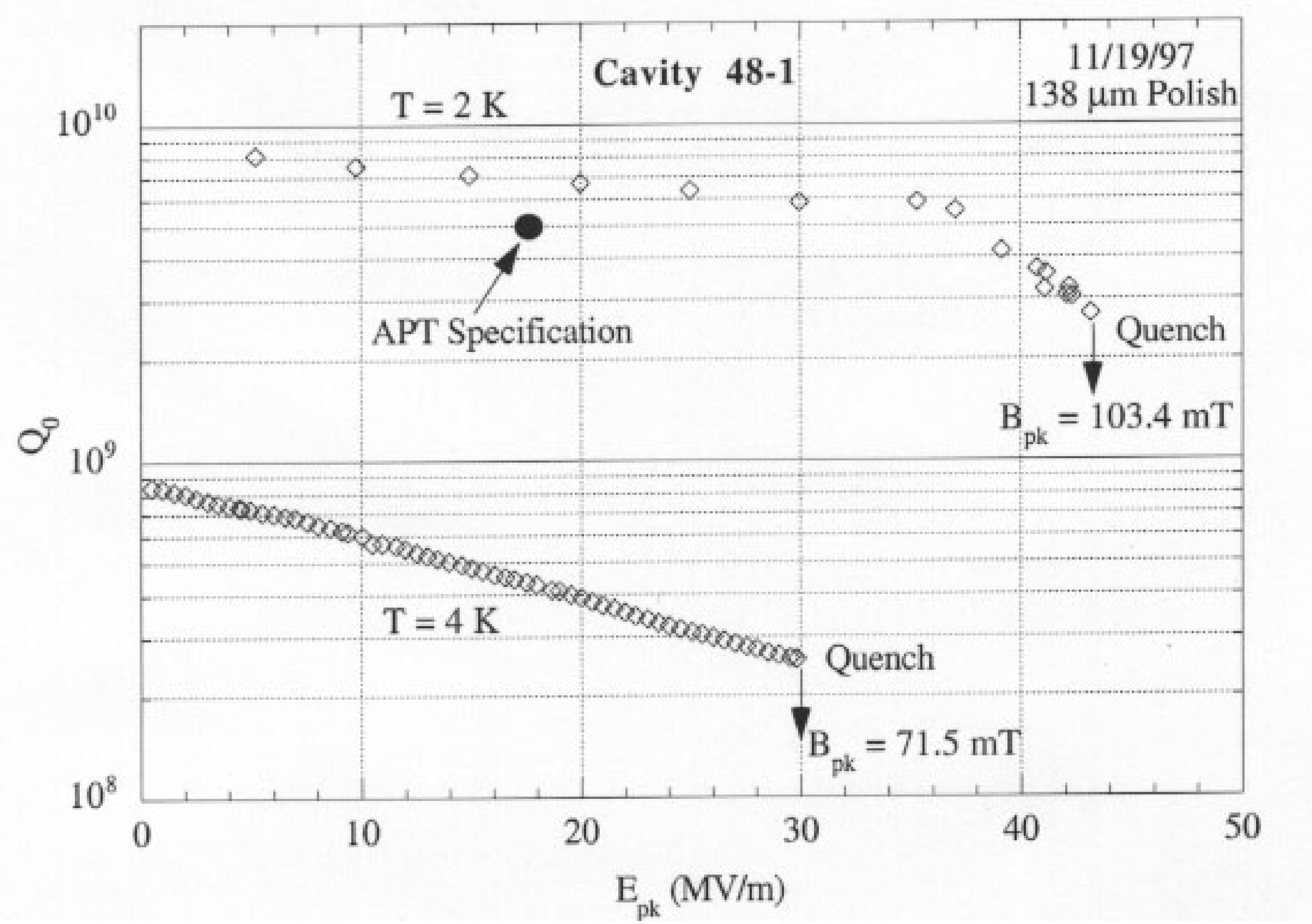


Project: 48 fab schedule-r2
Date: 4/4/01

Task | Milestone | Summary

48 fab schedule-r3.mpp | Page 1 | 4/4/01

Single-Cell Test Results from 1998



Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

SPOKE CAVITY STUDY

Dale Schrage
LANL/LANSCE-1

TECHNICAL REQUIREMENTS

- OPTIMIZE FOR ADTF @ 13.3 mA
- CAPABLE OF APT @ 100 mA
- OPERATE WITH HIGH RELIABLITY FOR THE ADTF APPLICATION
- FIT INTO EXISTING APT LINAC TUNNEL CROSS-SECTION

STUDY OBJECTIVES

- DETERMINE THE APPLICABILITY OF THE LOW-β SPOKE CAVITY TO AN OPTIMIZED ADTF DESIGN
- COMPARE NORMAL-CONDUCTING AND SUPERCONDUCTING OPTIONS FOR THE ADTF LOW-ENERGY LINAC (6.7 - 211 MeV)

STUDY TEAM MEMBERS

- Dominic Chan, Project Leader (APT/ED&D Project Leader) [PT]
- Matt Fagan, Thermal Analysis (APT/ED&D Project) [PT]
- Bob Garnett, Beam Dynamics (15 years' experience) [PT]
- Bob Gentzlinger, ANL Cavity Test, Tuner (APT/ED&D Cavities Task Leader) [FT]
- Brian Haynes, Power Coupler (APT Cavities & Power Coupler) [PT]
- Pat Kelley, Cryomodule & Cryoplant (15 years SC experience, from CEBAF, Chair of Board of Cryogenic Society of America) [PT]
- Frank Krawczyk, Cavity & Power Coupler RF Design (APT/ED&D Cavities & Power Coupler) [FT]
- Richard LaFave, Cavity Structural Analysis [FT]

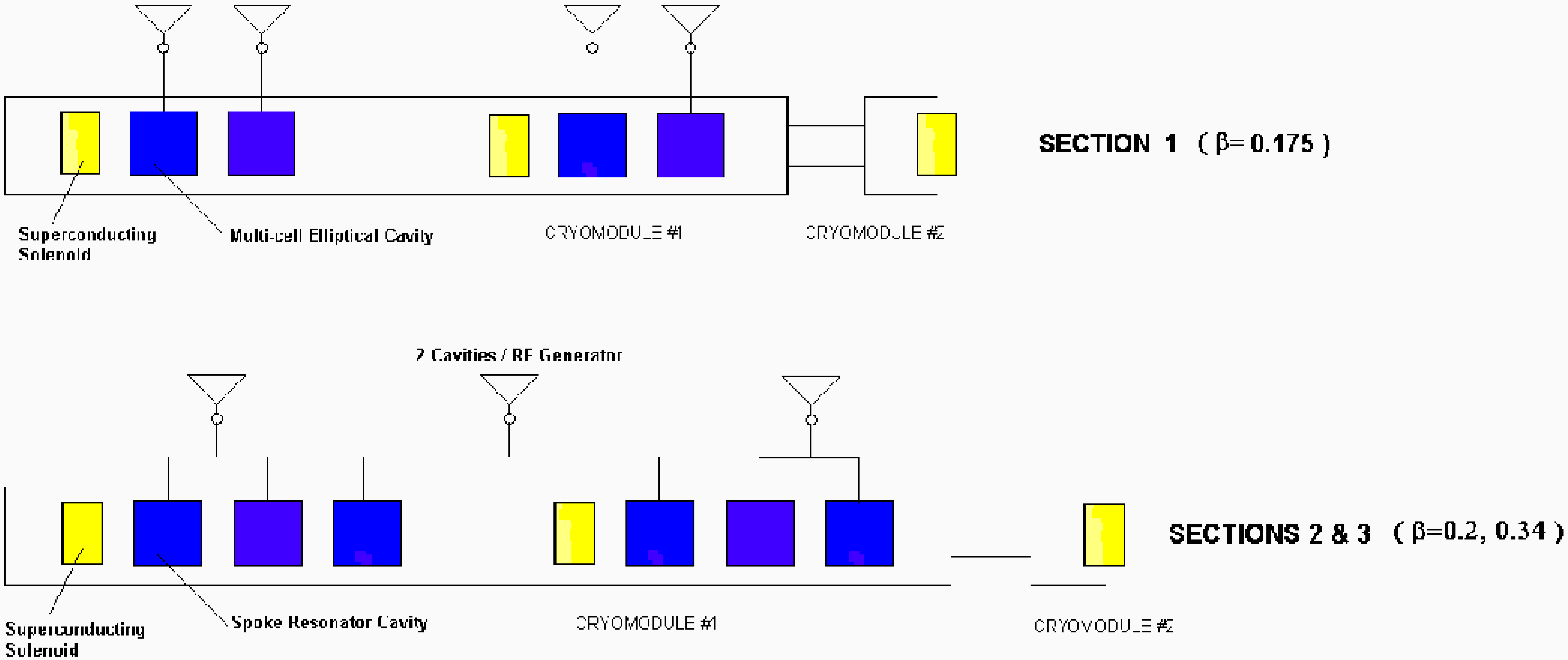
STUDY TEAM MEMBERS

- Mike Madrid, ANL Cavity Test (APT/ED&D Cavity Tests) [FT]
- Debbie Montoya, ANL Cavity Test (APT/ED&D Cavities Mechanical Design) [FT]
- Phil Roybal, Cryomodule (30 years' linac experience) [FT]
- Eric Schmierer, Power Coupler (APT/ED&D Power Coupler Task Leader) [PT]
- Dale Schrage, Chief Engineer (SC Cavities since 1988) [PT]
- Alan Shapiro, ANL Cavity Test (SC Cavities since 1988) [FT]
- Tsuyoshi Tajima, ANL Cavity Test (SC Cavities since 1985, from KEK) [FT]
- Tom Wangler, Beam Dynamics (30 years' experience, APS Fellow) [PT]
- Joe Waynert, Thermal Analysis (APT/ED&D Project) [PT]

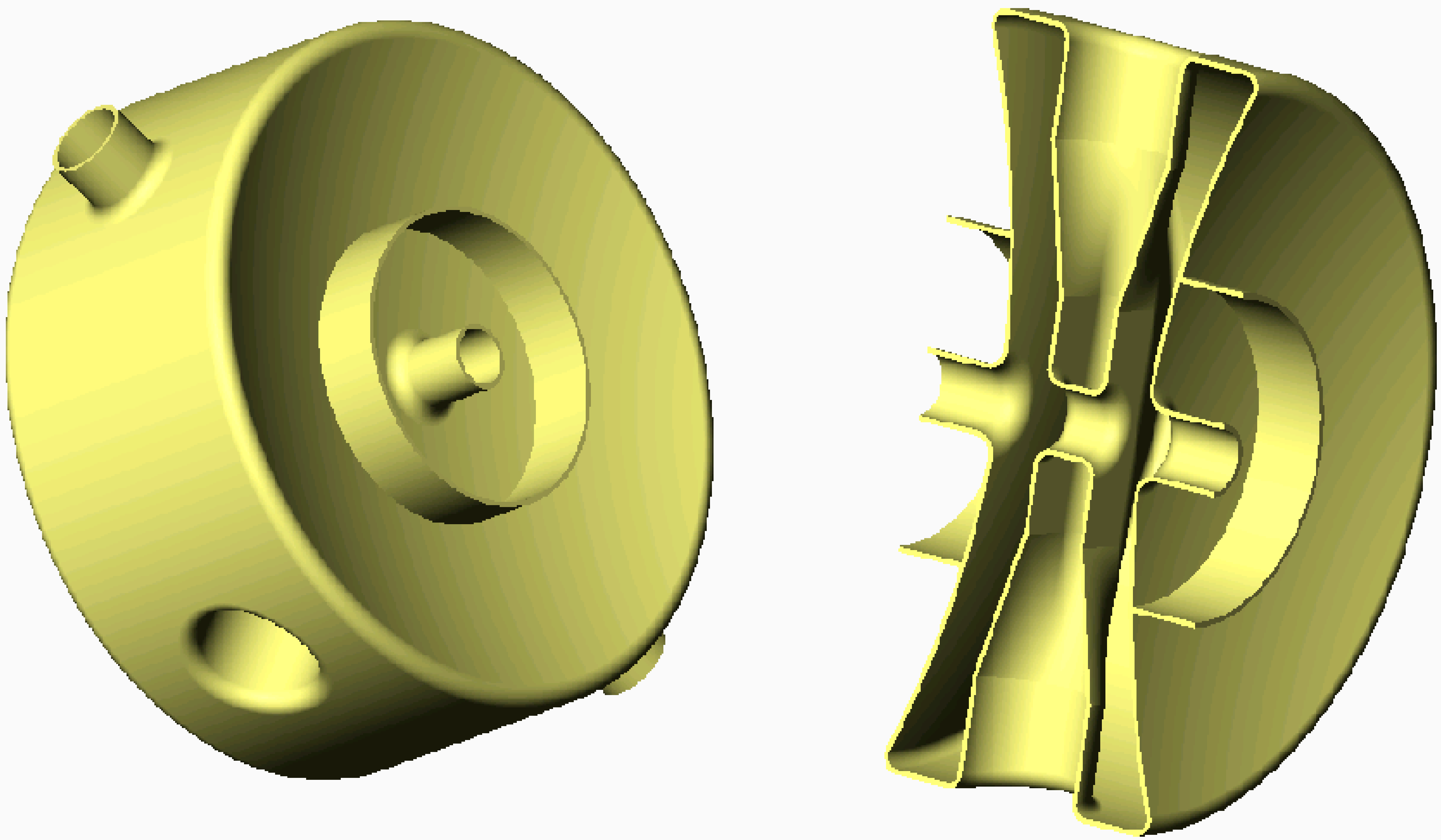
COLLABORATORS

- Jean Delayen, JLAB
- Jozef Kuzminski, GA
- Tim Myers, AES
- Ed Peterson, AES
- John Rathke, AES
- Brian Rusnak, LLNL
- Ken Shepard, ANL

LOW ENERGY ADTF LINAC



LANL/ADTF β = 0.175 2-GAP CAVITY



DETERMINE THE APPLICABILITY OF THE LOW-β SPOKE CAVITY TO AN OPTIMIZED ADTF DESIGN

- UNDERSTAND LOW ENERGY LINAC BEAM DYNAMICS
- RF & STRUCTURAL DESIGN OF CAVITIES
- TEST EXISTING ANL CAVITY
- ESTABLISH POWER COUPLER CONCEPT
- ESTABLISH CAVITY TUNER CONCEPT
- ESTABLISH CRYOMODULE CONCEPT

COMPARE NORMAL-CONDUCTING AND SUPERCONDUCTING OPTIONS FOR THE ADTF LOW-ENERGY LINAC

- RELIABILITY
- IMPLEMENTATION COST
- IMPLEMENTATION SCHEDULE
- OPERATING COST

STUDY CONSTRAINTS RESULTED IN INCOMPLETE CONCEPTS PLUS LARGE ERROR BARS ON COST AND SCHEDULE PREDICTIONS

- LIMITED TIME (December - March)
- LIMITED PERSONNEL (Most are Part-Time on this Project and have other high-priority assignments such as AHF & SNS)
- LIMITED FINANCIAL RESOURCES (Inhibited travel plus use of consultants and contract personnel services.)

SPOKE STUDY TECHNICAL REPORTS

LINAC DESIGN:

R. Garnett, "Revised Strawman S2 Design for ADTF Cost Comparision Basis, LANSCE-1:01-034, March 15, 2001

T. Wangler & R. Garnett, "Advance Superconducting Lianc Design Concept for ADTF Strawman S2," LANSCE-1:01-006(TN), February 8, 2001

R. Garnett, "Revised SC Design for ADTF Cost Comparison Basis," LANSCE-1:00-134, December 20, 2000

R. Garnett & R. Wood, "ADTF Cost Comparison Basis," LANSCE-1:00-119, December 6, 2000

SUPERCONDUCTING SOLENOIDS:

R. Garnett, "ATW Advanced Superconducting Design Example and the Use of SC Solenoids," LANSCE-1:00-070, August 16, 2000

SPOKE STUDY TECHNICAL REPORTS

SPOKE CAVITY DESIGN:

B. Rusnak, et al, "Spoke Cavity Design Review - Committee Report," March 13, 2001

F. Krawczyk, "Estimated Bandwidth for the ADTF Superconducting Cavity," LANSCE-1:01-015, March 9, 2001

F. Krawczyk, "Estimated RF Losses in the AAA Cavities, ADDENDUM," LANSCE-1:01-017, January 18, 2001

F. Krawczyk, "Estimated RF Losses in the AAA Cavities," LANSCE-1:01-008, January 18, 2001

F. Krawczyk, "Status of AAA Spoke Cavity Design Simulations," LANSCE-1:01-001, January 11, 2001

R. Garnett, "ATW $\beta = 0.175$ 2-Gap Spoke Cavity Transit-Time Factor, Again," LANSCE-1:00-083, September 18, 2000

SPOKE STUDY TECHNICAL REPORTS

SPOKE CAVITY DESIGN, con't:

R. Garnett, "ATW β = 0.175 2-Gap Spoke Cavity Transit-Time Factor," LANSCE-1:00-071, August 16, 2000

F. Krawczyk, "A Preliminary Estimate on an ATW Spoke Optimization," LANSCE-1:TN-00-023, May 5, 2000

R. LaFave, "Structural and RF Analysis of LANL 2 Gap, 350 MHz Spoke Resonator Cavity," LANSCE-1:01-002, January 11, 2001

SPOKE STUDY TECHNICAL REPORTS

POWER COUPLER:

J. Waynert, "Thermal Analysis on ADTF Spoke Cavity Power Coupler," ESA-EPE:01-075, March 30, 2001

Matt Fagan, "Scoping Sensitivities for Spoke Cavity Input Power Coupler Inner Conductor," ESA-DE:01-040, March 8, 2001

CRYOPLANT DESIGN:

P. Kelley, "Cryosystem Cost Estimates for a Superconducting Low Energy Linac for ADTF - December 20, 2000 Beam Transport Design," LANSCE-:01-008-TN, February 13, 2001

COST STUDY:

D. Schrage, "ADTF Low Energy Linac Cost Study - Results of Kickoff Meeting," LANSCE-1:01-010, January 26, 2001

SPOKE STUDY TECHNICAL REPORTS

ANL CAVITY:

F. Krawczyk, "Peak Surface Field Locations in the ANL Cavity," LANSCE-1:01-014, February 5, 2001

R. LaFave, "Resonant Structural Frequency Analysis of ANL 3-gap, 350 MHz β_g = 0.36 Spoke Resonator Cavity," LANSCE-1:00-078, September 12, 2000

R. LaFave, "Structural Analysis of Argonne National Laboratory 3-gap 350 MHz β_g = 0.36 Spoke Resonator Cavity,"LANSCE-1:00-069, August 14, 2000

LIST OF PRESENTATIONS

- TEST OF ANL SPOKE CAVITY - *TSUYOSHI TAJIMA*
- DESIGN OF SPOKE CAVITIES - *FRANK KRAWCZYK*
- SPOKE CAVITY POWER COUPLER CONCEPT - *ERIC SCHMIERER*
- CRYOMODULES & CRYOPLANT - *PAT KELLEY*
- ED&D PLAN - *DALE SCHRAGE*

AAA

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

ANL Spoke Cavity Tests

Tsuyoshi Tajima
Alan Shapiro, Mike Madrid, Frank Krawczyk, Richard LaFave, Brian Haynes, Bob Gentzlinger, Debbie Montoya, Randy Edwards

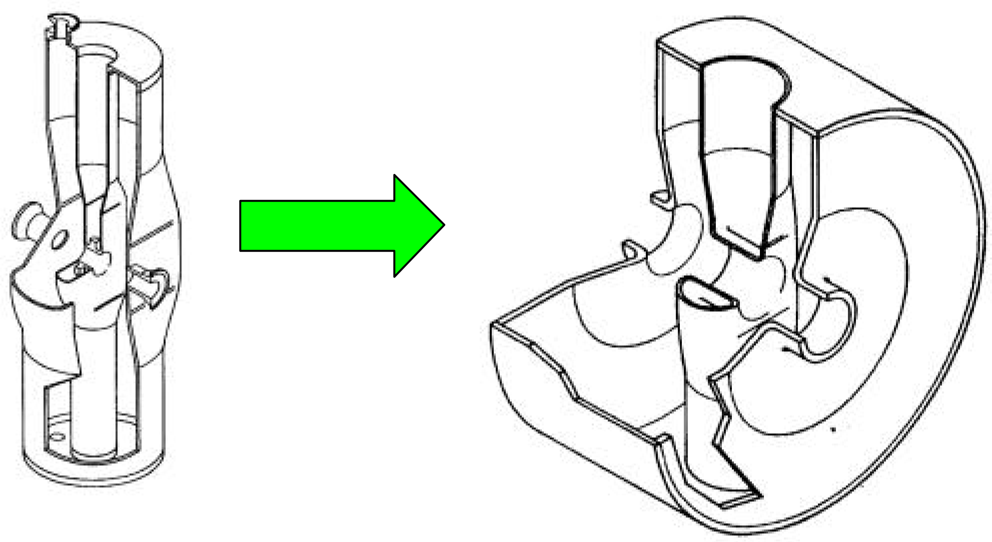
Objectives of ANL Spoke Cavity Test

- Familiarize ourselves with this type of cavity
- Benchmark simulation codes for designing
- Validate applicability of our technology for APT cavities to spoke cavity
  - Buffered Chemical Polishing (BCP)
  - High-Pressure Rinsing (HPR)
  - Clean assembly and preparation
  - RF measurement procedure
- Predict achievable cavity accelerating field E_{acc} and quality factor, Q_0.

History of Spoke Cavity Development

AAA

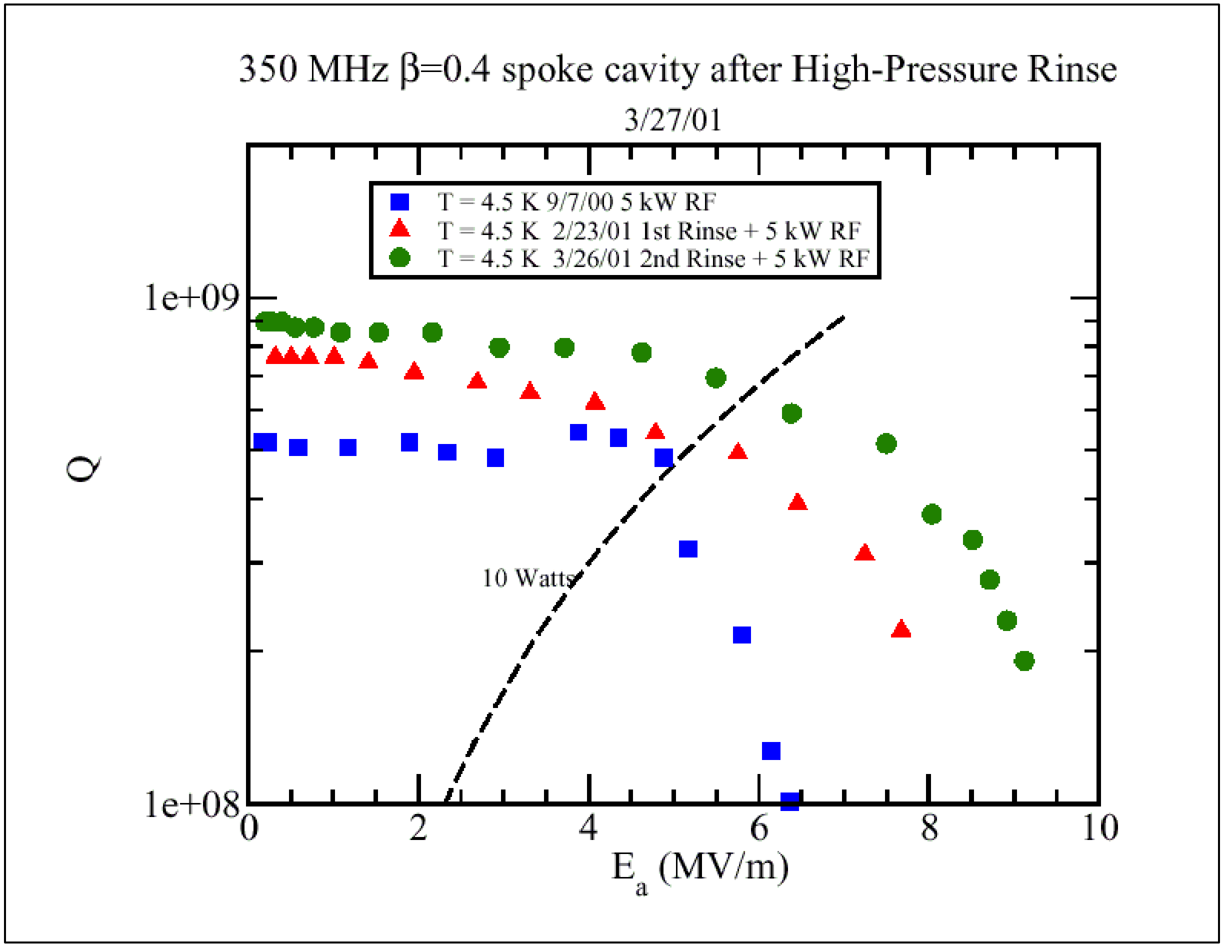
- Started at Argonne National Laboratory (ANL) in 1991 for acceleration of high-current ion beams to high velocity.
- A modification of coaxial half-wave/quarter-wave resonator because:
  - This geometry is easier to fabricate reliably
  - It can be straightforwardly extended to multi-gap designs.



History of Spoke Cavity Development

- **A 2-gap, 855 MHz, b=0.30 cavity was fabricated and tested successfully (1991-1992). E_{acc}=7.2 MV/m (CW)**
- **Lower frequency spoke cavities were designed to allow:**
  - **Larger bore radius**
  - **Reduction of number of cavities (more economical)**
- **Two 2-gap, 350 MHz, b=0.3/0.4 cavities were fabricated and tested at ANL (1998-).**
  - **So far, the highest field of 9 MV/m has been obtained with b=0.4 cavity (conditioned with 5 kW high power pulse in addition to high-pressure rinsing).**

History of Spoke Cavity Development (Test result at ANL)



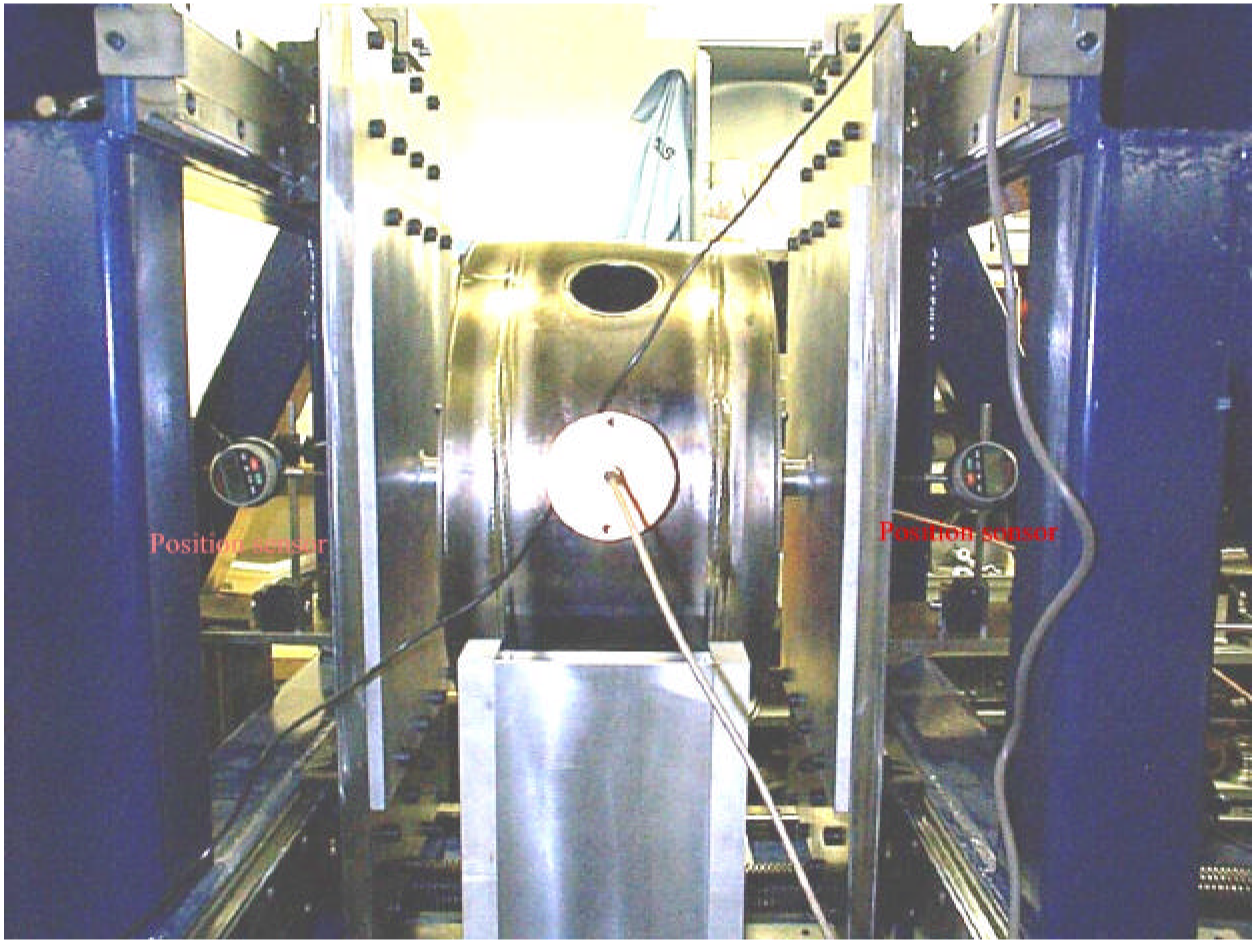
Spoke Cavity on Loan from ANL

- Frequency 340 MHz
- β = 0.291
- Made of bulk Niobium (housing 1/8 in, central spoke 1/16 in. thick)
- Parts 150 μm electro-polished before fabrication
- BCP 50 μm after fabrication
- High-pressure spray rinse
- Tested at ANL at 4.5 K (E_{acc} ~5 MV/m, ~7 MV/m with heavy electron loading)

Tests Using ANL Spoke Cavity

- At room temperature,
  - Tuning sensitivity measurement and comparison with simulation codes
  - Axial field profile measurement and comparison with simulation codes
- At low temperature (4 K ~ 2 K),
  - Quality factor versus accelerating field measurement at 4 K and 2 K
  - Quality factor versus temperature measurement
  - Surface resistance (inversely proportional to quality factor)

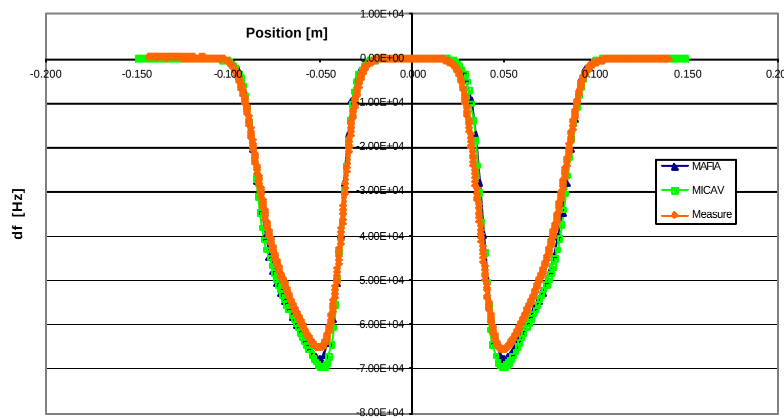
Room Temperature Tests



Summary of Room Temperature Tests

AAA

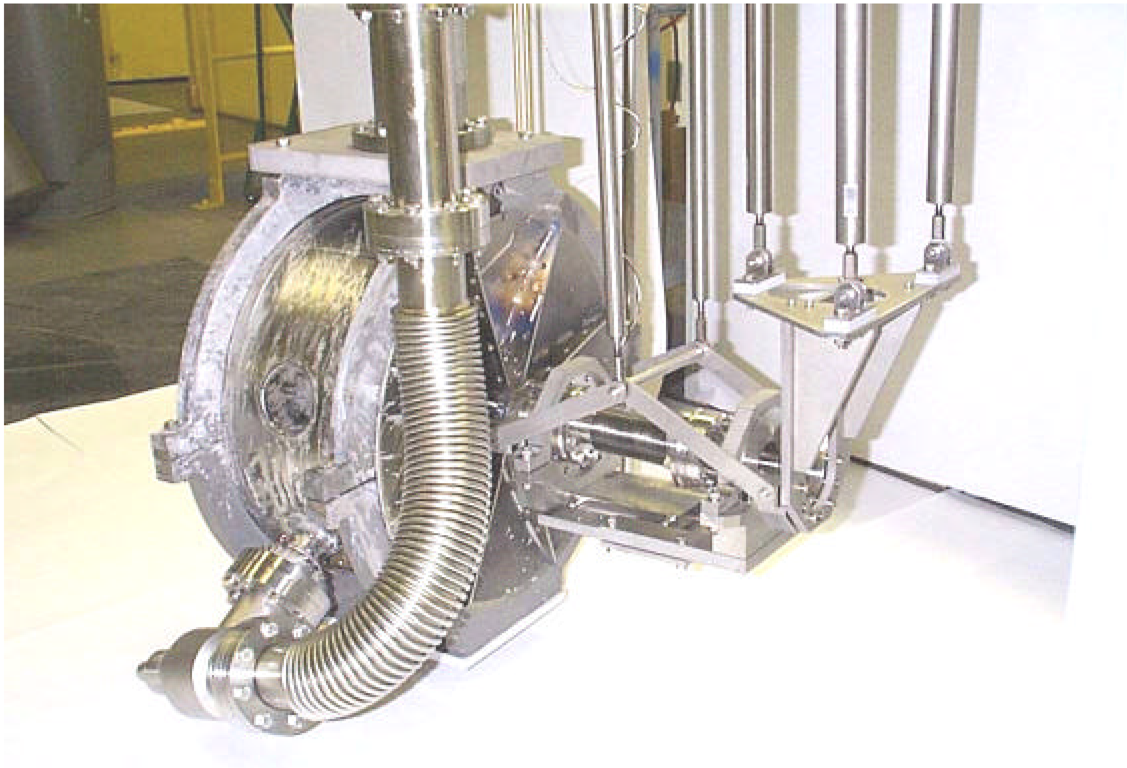
- **Frequency: 339.6994 MHz (Calculation was 0.26 % lower.)**
- **Tuning sensitivity: 9.356 MHz/in. (Calculation was 20 % higher)**
- **Spring stiffness: 34.4 lb/mil. (calculation was 29 % higher)**
- **Results of field profile measurement showed uniform deformation while tuning. Also, simulation results showed excellent agreement with measurement as shown below.**



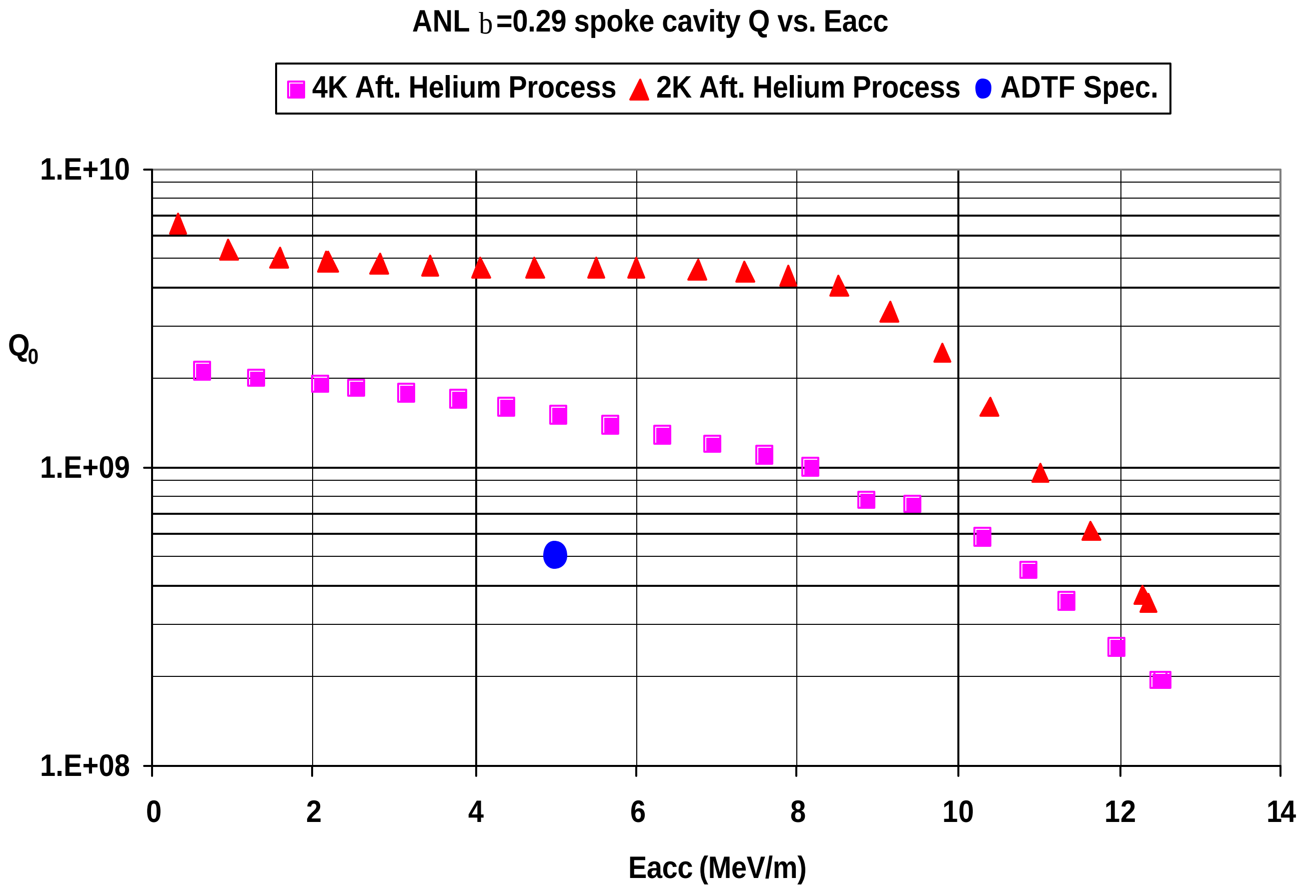
Low Temperature Tests

- **Preparation and testing**
  - **Surface was etched 100 μm to remove field emission source(s)**
  - **High-pressure (1000 psi) rinse with ultra-pure water in the class-100 clean room**
  - **Assembly of RF couplers, vacuum valve, etc. in the clean room**
  - **Pump down and baking at 150 °C on the spoke and 80 °C at indium joints**
  - **Insert the cavity into cryostat and pre-cooled to 250 K by filling outer layer of cryostat with liquid nitrogen**
  - **Fill cryostat with liquid helium to cool down cavity to 4 K**
  - **After the measurement at 4 K, pumped down cryostat to cool down further to 2 K (24 Torr) or below**

Low Temperature Tests



Test Results @ 4 K and 2 K



Summary of ANL Cavity Tests

- Successfully benchmarked simulation codes with the tests at room temperature
- Results of low temperature tests showed:
  - High quality of our preparation techniques
  - Full applicability of our superconducting laboratory facilities to the testing of spoke cavities
  - High gradients (>12 MV/m) and high quality factor ($2x10^9$ at 350 MHz and 4 K) can be achieved with spoke cavities.

TPO-RGN-1003

AAA

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 12, 2001

Design of the Spoke Cavities

Frank Krawczyk
Richard LaFave
Brian Haynes, Eric Schmierer, Dale Schrage, Tsuyoshi Tajima

Objectives

AAA

- Provide βs and geometries of cavities:
  Real estate gradients, achievable energy gains
- Provide interface requirements with subsystems:
  Main coupler, vacuum, diagnostics
- Provide mechanical properties:
  Stiffening, tuning forces, tuning ranges
- Provide RF losses at operating field level

⇓

1 Length and layout of accelerator
2 Layout of cryomodules
3 Sizing of cryosystem
4 Cost
5 Performance comparisons

Advantages of Spoke Resonators

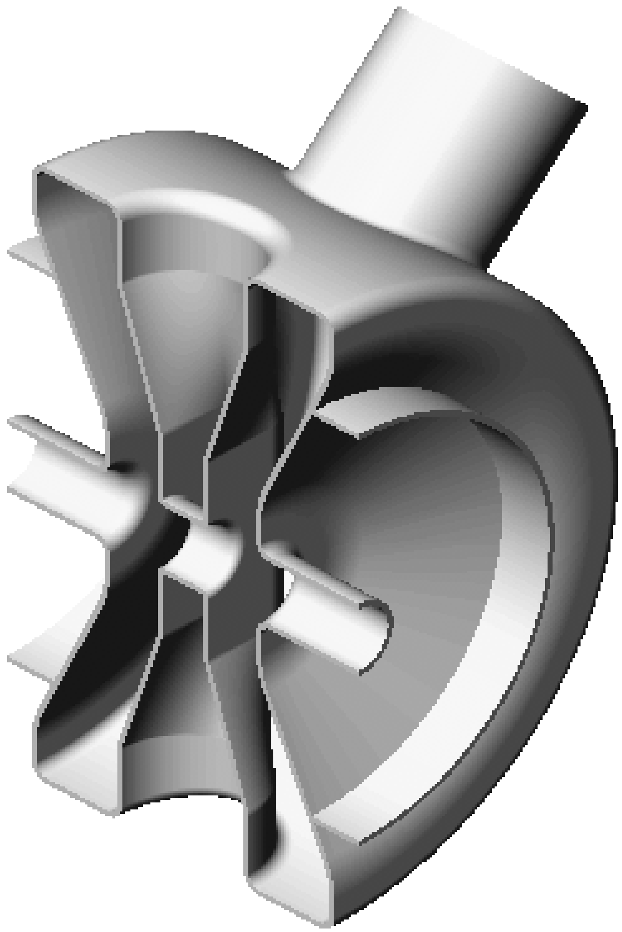
- High mechanical stability (pill-box with internal bar)
- Can be used at lower β than elliptical cavities
- Diameter: λ/2 instead of λ (350 MHz cavity size comparable to 700 MHz elliptical structure)
- Peak field ratios of β=0.175 structure comparable to β=0.64 elliptical cavity
- Gap-to-gap coupling independent of beam pipe aperture

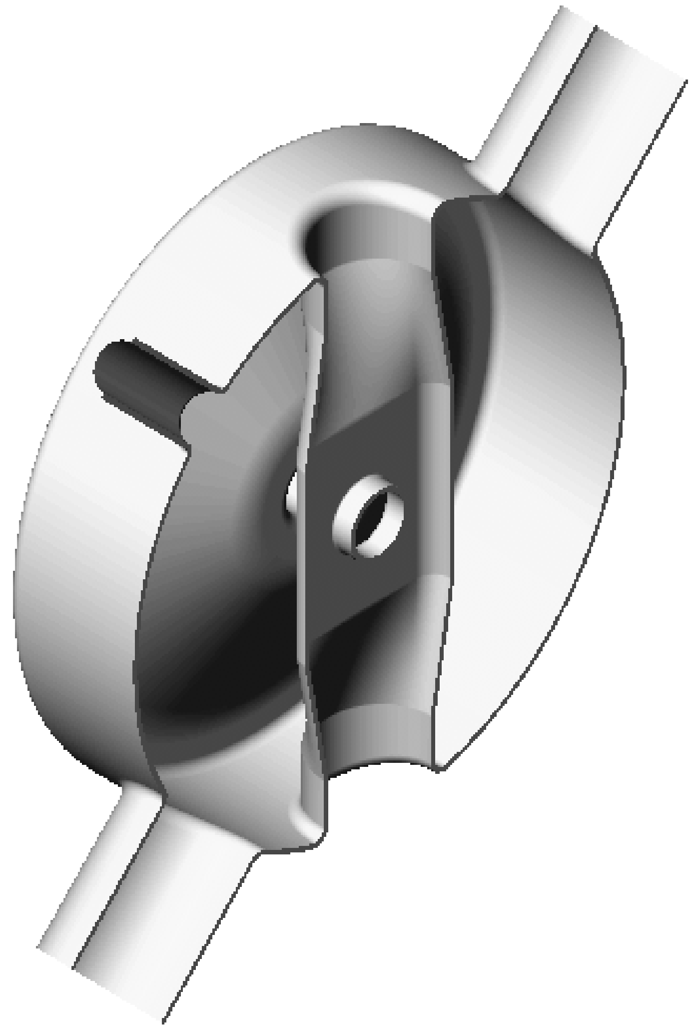
Spoke Resonator Design Issues

AAA

- Interaction of beam-dynamics simulations, RF and mechanical properties:
  - β=0.175, 2-gap resonator (lowest reasonably effective β)
  - β=0.2, 3-gap resonator (increase of real-estate gradient)
  - β=0.34, 3-gap resonator (good match between low β structures and β=0.48 elliptical cavity)
- RF design has to be integrated cavity-coupler design
- Achievable gradients driven by peak field ratios: Established procedures focus on spoke shape and end-wall choice (see Delayen (Jlab), Shepard (ANL))

β = 0.175 2-Gap Spoke Resonator Geometry





RF Design and Properties

AAA

	0.175	0.200	0.340	ANL 0.3	APT 0.64
Frequency [MHz]	350	350	350	350	700
T_g	0.796	0.787	0.769	-	0.650
T_{max}	0.811	0.790	0.777	0.910	0.700
Q_0 (70/16 nΩ)	1.72E+09	1.34E+09	1.28E+09	1.01E+09	9.40E+09
ZT^2/Q [W]	134	214	318	295	191
E_{pk}/E_0T	2.84	< 3.60	< 3.47	3.18	3.38
B_{pk}/E_0T [G/MV/m]	69	< 96	< 104	85	70
G [Ω]	120	94	90	70.7	149
Q_x (nom.)	1.90E+05	1.10E+05	1.10E+05	-	2.00E+05
E_0T (nom.) [MV/m]	5.00	5.00	5.00		6.00
B_{pk} @ E_0T [G]	350	TBD	TBD	-	420
B_{pk} in testing * [G]	-	-	-	1000	840

* on test stand @ 12 MV/m

Optimized Geometry

Non-Optimized Geometry

Mechanical Properties

- Vacuum loading at 2 Atm:
  - Variation with stiffening ring diameter
  - Optimized for β=0.175
  - Stresses < 75% Nb yield at room temperature
  - Frequency change < 100 kHz
- Tuning sensitivities:
  - Variation with stiffening ring diameter
  - Optimized for β=0.175
  - Maximum excursion: stresses < Nb yield strength at room-temperature
  - Tuning range: at least ± 140 kHz
- Lowest mechanical resonances:
  - longitudinal/torsional
  - All modes above 270 Hz

Result of Design Review for β=0.175 Spoke

AAA

Findings

Review by Delayen, Rusnak, Shepard (01/23/2001)

RF design advanced (β=0.175 cavity ready for final design)

Mechanical design good

Overall project (beam dynamics, coupler, tuner, cryostat,) needs to catch up

Recommendations

4K is desired operation temperature (2)

Get obtainable/required Q_{ext} for 100 mA beam (2)

Complexity reduction by using a "standard" coaxial coupler? (yes, 2)

HOMs: only concern would be potential of resonant excitation of mode by bunch repetition (TBD)

Do not over design cleaning capability, so far operation was good even for simple cleaning procedure (depends on desired gradients, see ANL cavity test)

Results from Spoke Design Work

- Beam-dynamics: ⟶ Cavity-βs, transit-time factors, achievable gradients
- For beam-test: ⟶ Fully optimized β=0.175 cavity
- RF performance: ⟶ Peak field ratios $\Rightarrow$ gradients of > 5 MV/m
- Cavity-coupler system: ⟶ Electric coupling meets required Q_{ext} $\Rightarrow$ lower complexity and cost
- Mechanical properties: ⟶ Vacuum loading $\Rightarrow$ stiffening; Tuning forces/sensitivities $\Rightarrow$ tuner specs
- Cryostat: ⟶ Designs with all subsystems compatible with space envelope
- Cryo-system: ⟶ Cavity RF loads $\Rightarrow$ cryo-plant design
- All spoke geometries: ⟶ Common port-sizes for main coupler, Diagnostics ports $\Rightarrow$ Lower cost, effort

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

Power Coupler Design Concept for the Low-Energy Linac

Eric Schmierer

(Matt Fagan, Brian Haynes, Frank Krawczyk, Phil Roybal, Joe Waynert)

Overview

- Power coupler requirements for sections 1-3 (beta = 0.175, 0.2, and 0.34 spoke cavities)
- Design objectives and approach
- RF characteristics
- Conclusions

Spoke Cavity
Input Coupler Power Requirements

section	cavity β	cavity type	couplers per section (one per cavity)	power requirement (kW, CW) 13.3 mA beam current	power requirement (kW, CW) 100 mA beam current
1	0.175	2-gap spoke	32	5.2	39.3
2	0.2	3-gap spoke	48	10.3	77.8
3	0.34	3-gap spoke	48	18.1	135.7

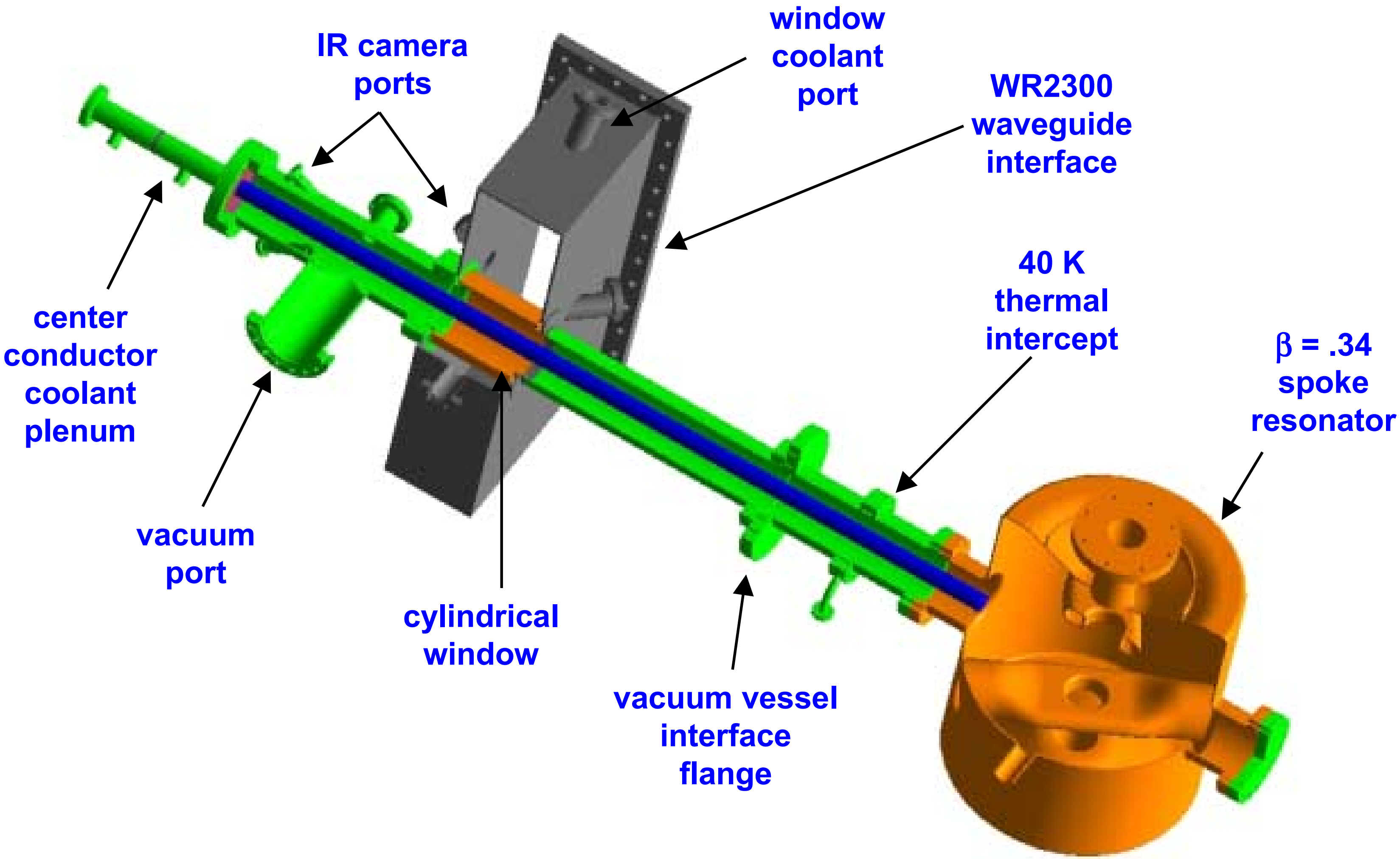
Design Objectives and Approach

1) Simple coupler design:
   - we selected an antenna-type concept based on the KEK TRISTAN normal-conducting design (225 kW, CW to beam)
   - the design concept is less complicated than the APT ED&D coupler however retains its advantages

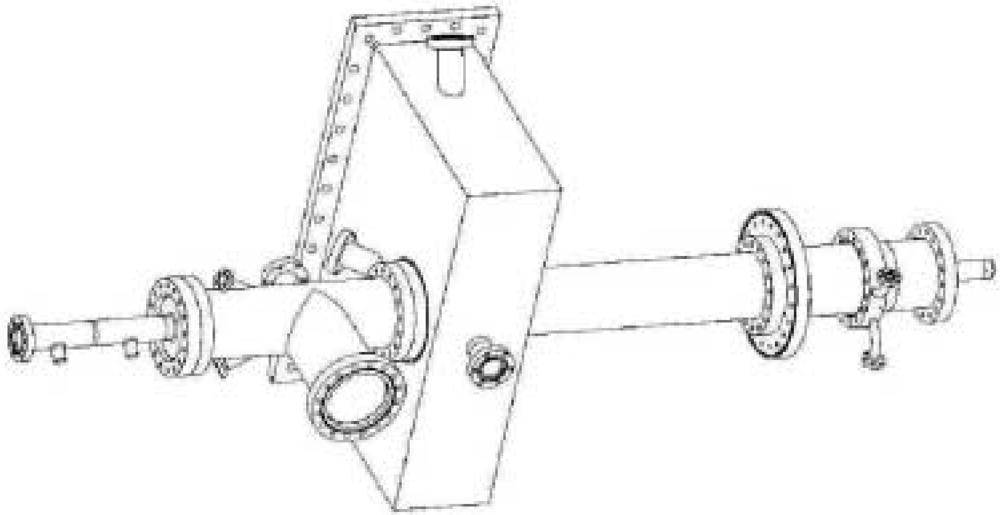
2) Minimal effort for beam current changes:
   - one design for all spoke cavities capable of 100 mA beam current operation (~140 kW, CW power transmission)
   - increasing from 13.3 to 100 mA only requires adjustment of the center conductor length

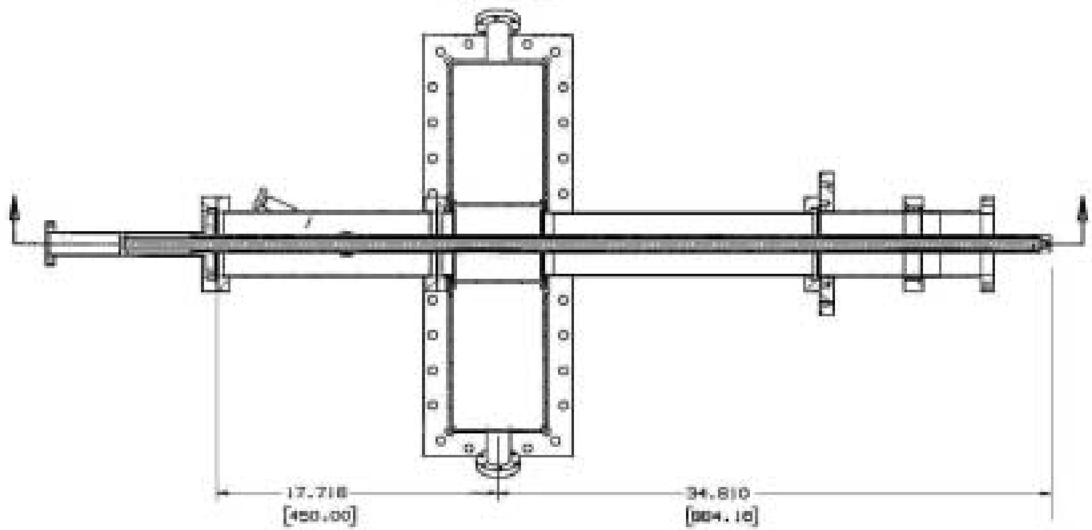
3) Design must be producible by industry:
   - industrial experience exists with similar coupler components e.g. Toshiba Co. (Japan), Hitachi-Haramachi Co. (Japan), CPI (USA), and EEV (UK)
   - no new processes or technology are incorporated in concept

Power Coupler Schematic



Power Coupler Isometric and Section View





Coax Dimensions and Multipacting

AAA

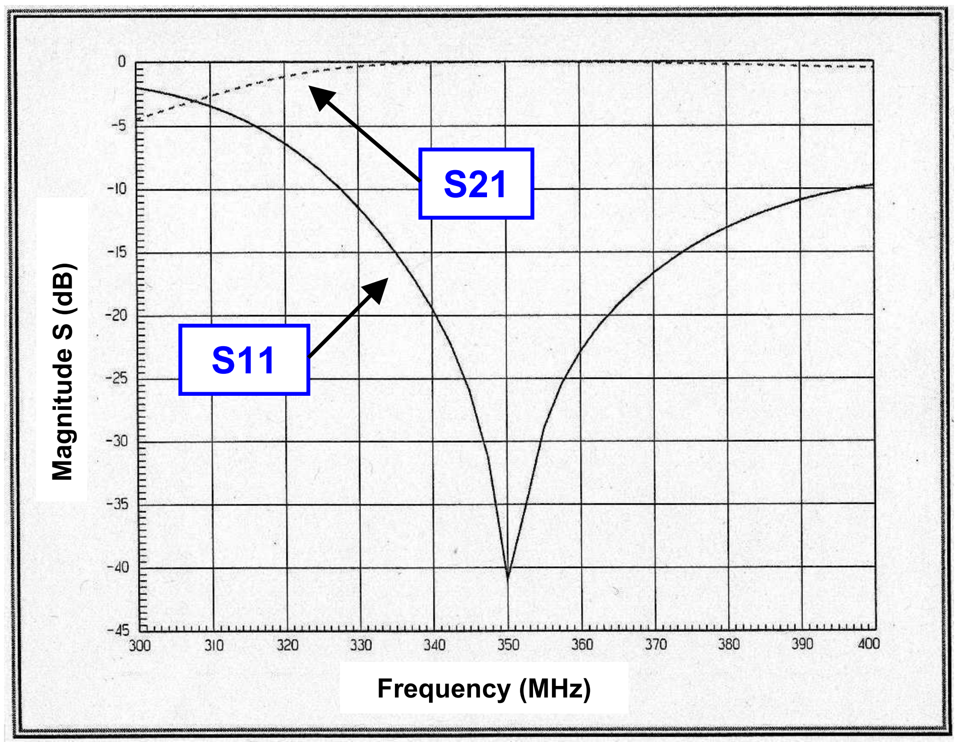
- The coax was sized to avoid the known multipacting power bands scaled from the experience of CERN
- 75 Ohm, 100 mm dia. was chosen

Band encountered for 100 mA   Band encountered for 13.3 mA

diameter (mm)	100	100	75	75	50
impedance (Ohm)	75	50	75	50	50
MP Order	multipacting power band average power (kW)				
7	48	32	15	10	2
6	52	36	16	11	2
5	88	60	29	19	4
4	176	118	56	37	7
3	234	152	72	48	10
2	448	300	146	97	19
1	640	428	203	136	27

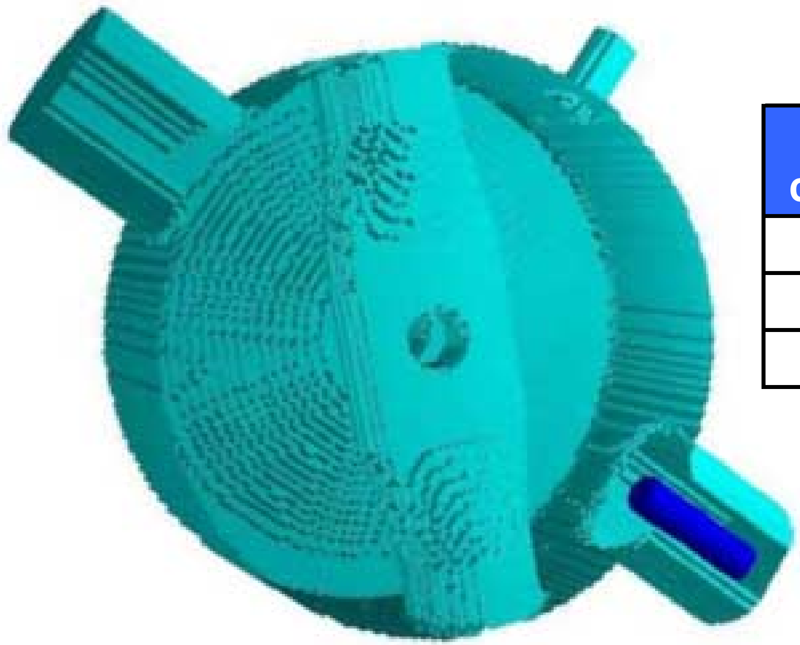
RF Match

- The power reflection was minimized using HFSS
  - reflection coefficient, S11 = -41 dB (0.008 %)
  - bandwidth +14 / -10 MHz at S11 = -20 dB (1 %)



RF Coupling to Cavity

- Our MAFIA calculations for Q_{ext} were verified by experiments on the ANL spoke cavity
- We can achieve the required Q_{ext} by coupling to the cavity electric field with an antenna tip



MAFIA model of β = 0.175 cavity w/ coupler tip

For 100 mA

cavity β	Qext required	Qext calculated with MAFIA*
0.175	1.9E+05	7.0E+04
0.2	1.1E+05	7.0E+04
0.34	1.1E+05	TBD

*calculated with flush tip condition

AAA

Coax Length was Optimized by a Balance of these Factors

Factor	Goal	Affect on Length
thermal standoff in vacuum tank	minimize refrigerator heat load	increase
pumping speed at ceramic window	mimimize pressure and conditioning time	decrease
overall dimensions of coupler	minimize envelope in tunnel	decrease
standing wave locations	minimize electric fields at ceramic window	increase

Conclusions

- A design concept based on a successful coupler operating at KEK has been chosen
- The design is simple while retaining the advantages of the successful APT ED&D coupler
- It has been optimized for avoiding multipacting and for good RF transmission
- We are poised to begin detailed design

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

Low Energy Linac (LEL) Spoke Cavity Cryomodule and Refrigeration

J.P. Kelley
P. Roybal, R. LaFave, R. Gentzlinger, J. Waynert

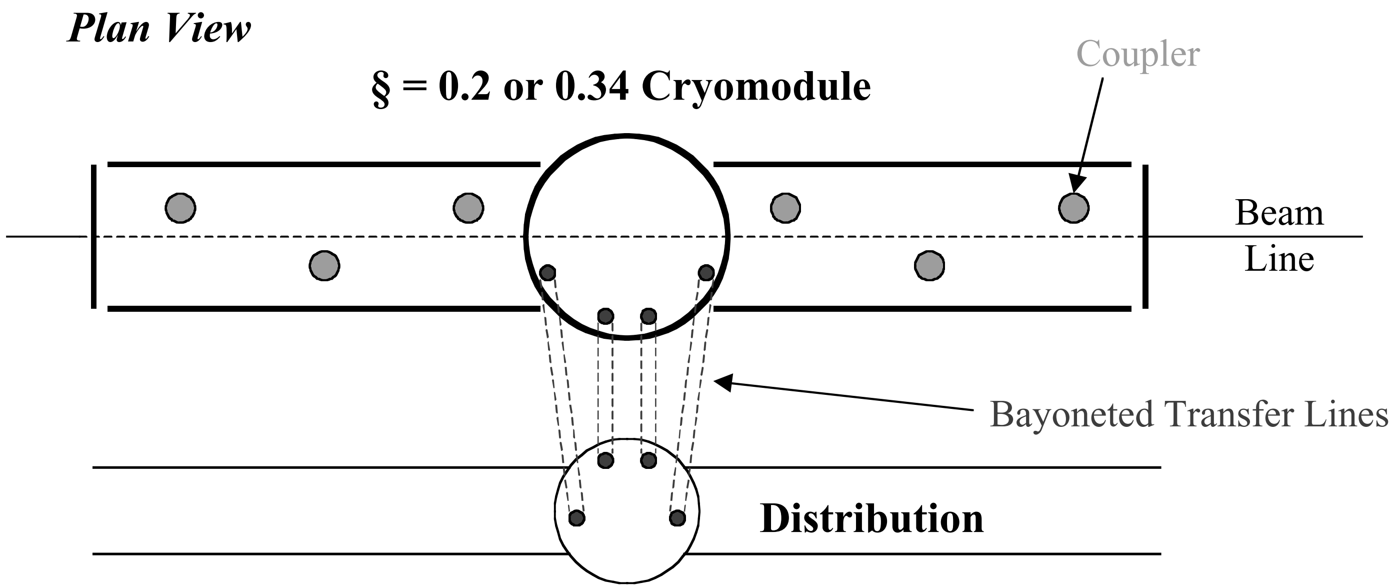
Cryomodule Overview

AAA

- ¥ Cryomodule Purpose
  - —House superconducting beam transport elements
    - ¨ Cavities and Solenoid Magnets
  - —Provide ingress and egress of:
    - ¨ Power, Instrumentation, Cryogens
  - —Fit in the APT Tunnel
- ¥ LEL Cryomodule Types (2)
  - —Spoke Cavity Modules (3 different lengths - § = 0.175, 0.2 and 0.34)
  - —Elliptical Cavity Modules (§ = 0.48)
- ¥ Focus of Presentation
  - —§ = 0.34 Spoke Cavity Cryomodule.
    - ¨ Elements shown are similar to all ADTF spoke cavity cryomodules.
- ¥ Goal
  - —Provide a design that can easily be built by industry
    - ¨ Accel, CERCA and Ansaldo have all built cryomodules

Spoke Cavity Cryomodule Form

- ¥ **Physical Form**
  - —Driven by beam physics.



  - —Similar to that of PETRA and HERA at DESY
    - ¨ Ingress and egress of cryogens at center of module
  - —Permits axial assembly approach
    - ¨ Axial assembly used by PETRA, HERA, TESLA, CEBAF, CEBAF Upgrade, SNS, TRISTAN, KEK-B

Spoke Cavity Cryomodule - Flowsheet Details

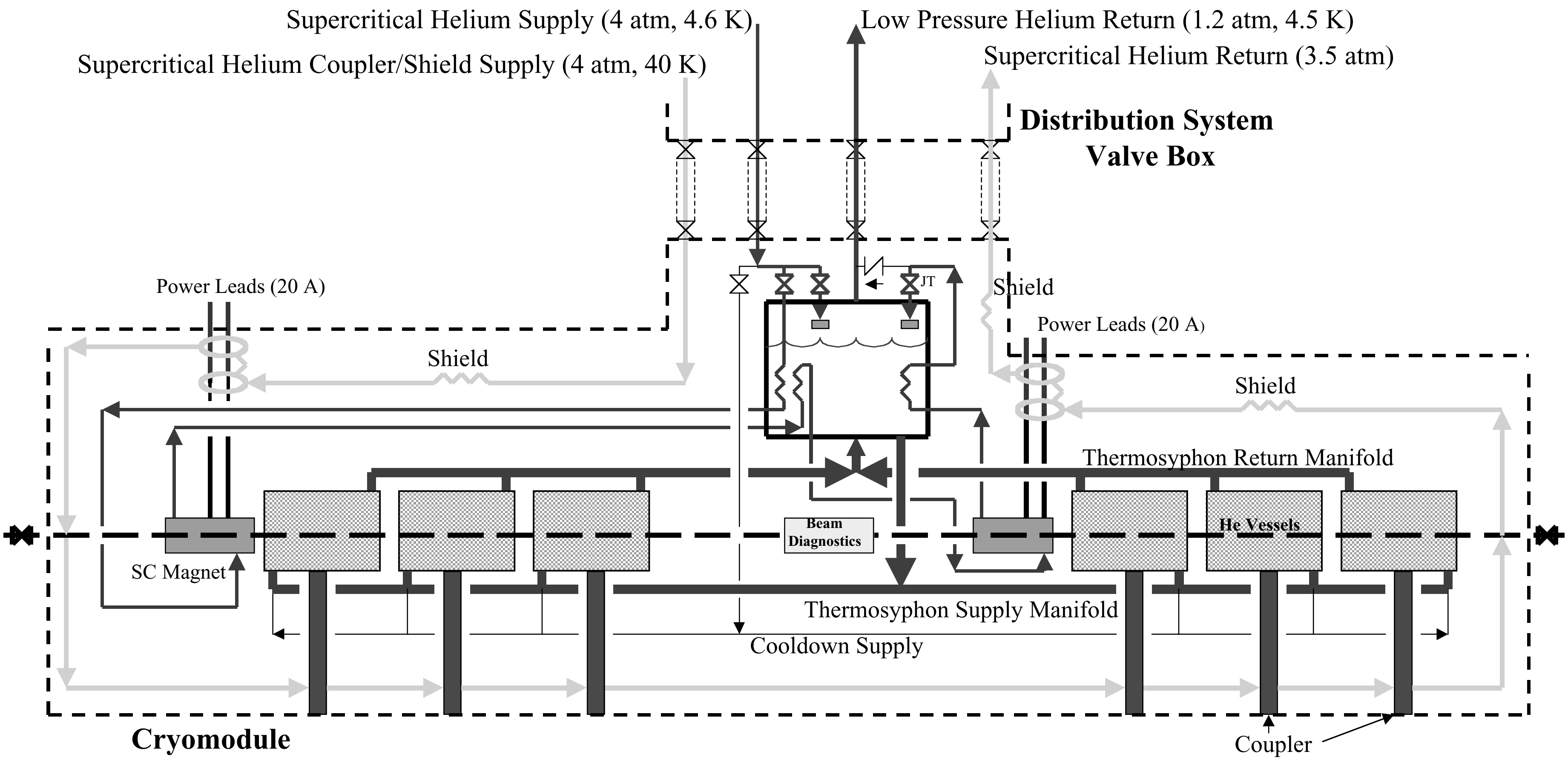
AAA

¥ **Cavity Cooling**
- —Thermosyphon Driven Flow

¥ **Solenoid Magnet Cooling**
- —Supercritical Helium Forced Flow (4 atm, 4.5 K)
- —Conduction Cooled Current Leads (20 A/magnet)

¥ **Shield/Intercept Cooling**
- —Supercritical Helium Forced Flow (4 atm, 40 K)

Spoke Cavity Cryomodule - Flowsheet



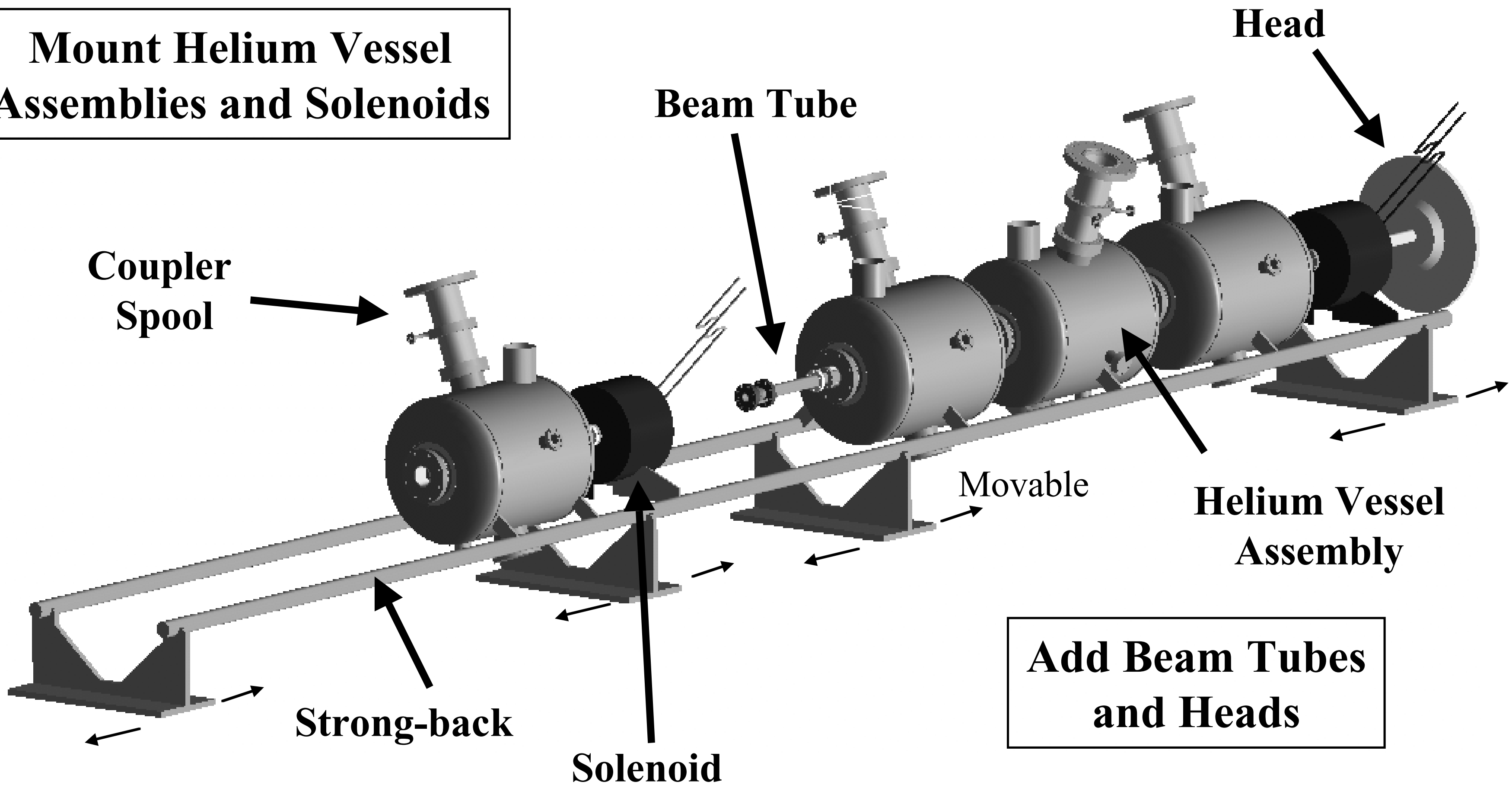
Spoke Cavity Cryomodule Clean Room Assembly

AAA

- Known - relative positions of beam center line, coupler inner flange and foot pads.
- Helium vessel assemblies (cavity/coupler/helium vessel)
  - Are mounted on pre-aligned strong-back
  - Fiducials are added to outer coupler flanges (for relating position of beam tube centerline to coupler outer flange)
  - Beam tubes are installed.
  - Temporarily locked-down to strong-back
- Solenoid magnet assemblies
  - Are mounted on the strong-back.
  - Beam tubes are installed (cavity to solenoid, solenoid to ambient).
- Transfer alignment data to fiducials on outer coupler flanges
- Final lock-down to strong-back

Spoke Cavity Cryomodule <u>Clean Room</u> Assembly - Figure

Mount Helium Vessel Assemblies and Solenoids



Add Beam Tubes and Heads

Spoke Cavity Module Final Cold Mass Assembly

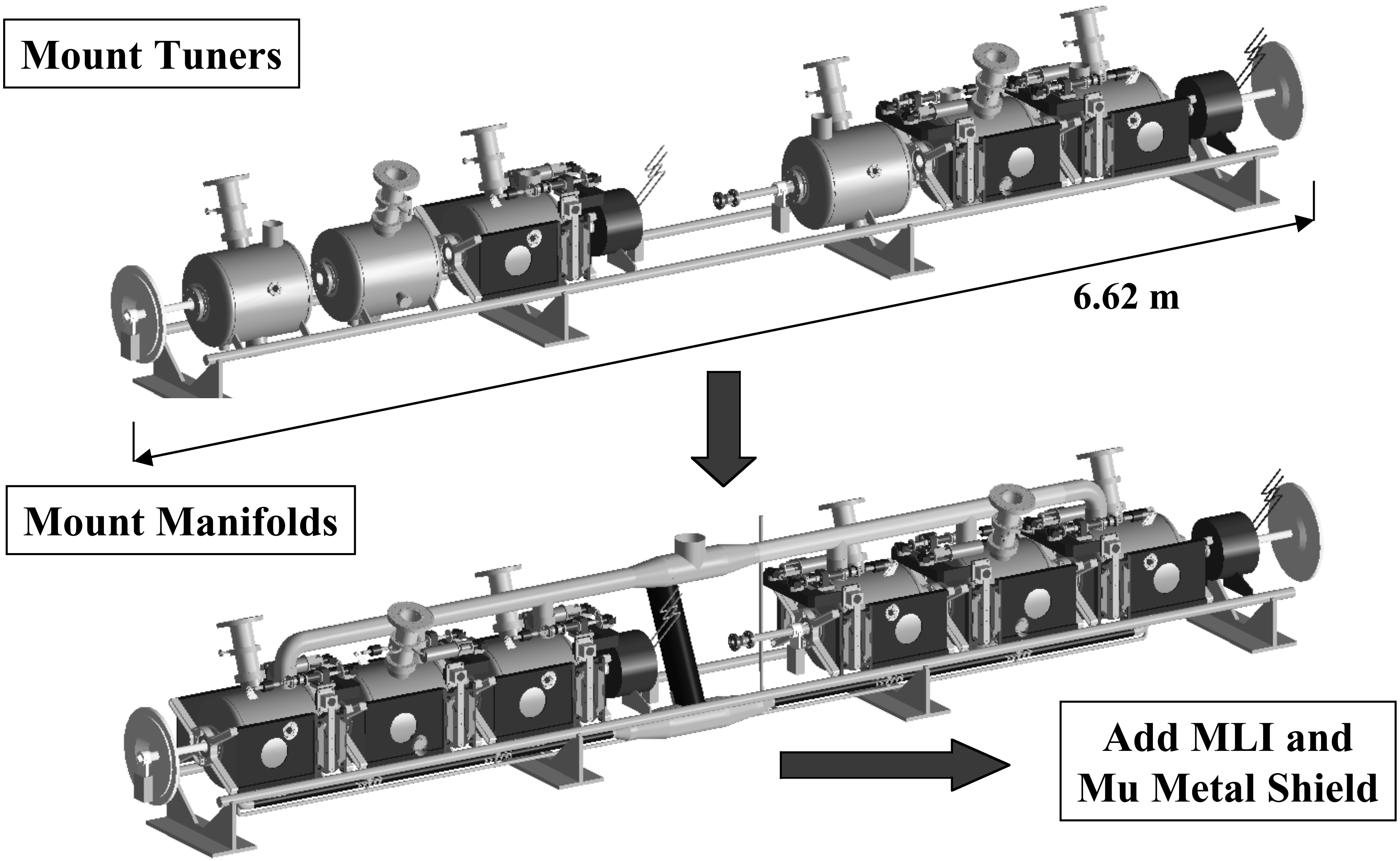
- Remainder of assembly performed outside the clean room

- Mount tuner assemblies
  - Tuner - Same as the APT Tuner
  - Cold Motor - Saclay-TESLA-SNS Pedigree
  - Piezoelectric actuator - Used by Saclay
    - Allows for cavity detuning in < 300 msec.

- Mount manifolds
  - 2   tube supply, 4 tube return, 1/2   tube cooldown supply

- Add multilayer insulation blanket (MLI - 15 layers) and Mu metal shield (0.040   thick)

Spoke Cavity Module Final Cold Mass Assembly - Figure



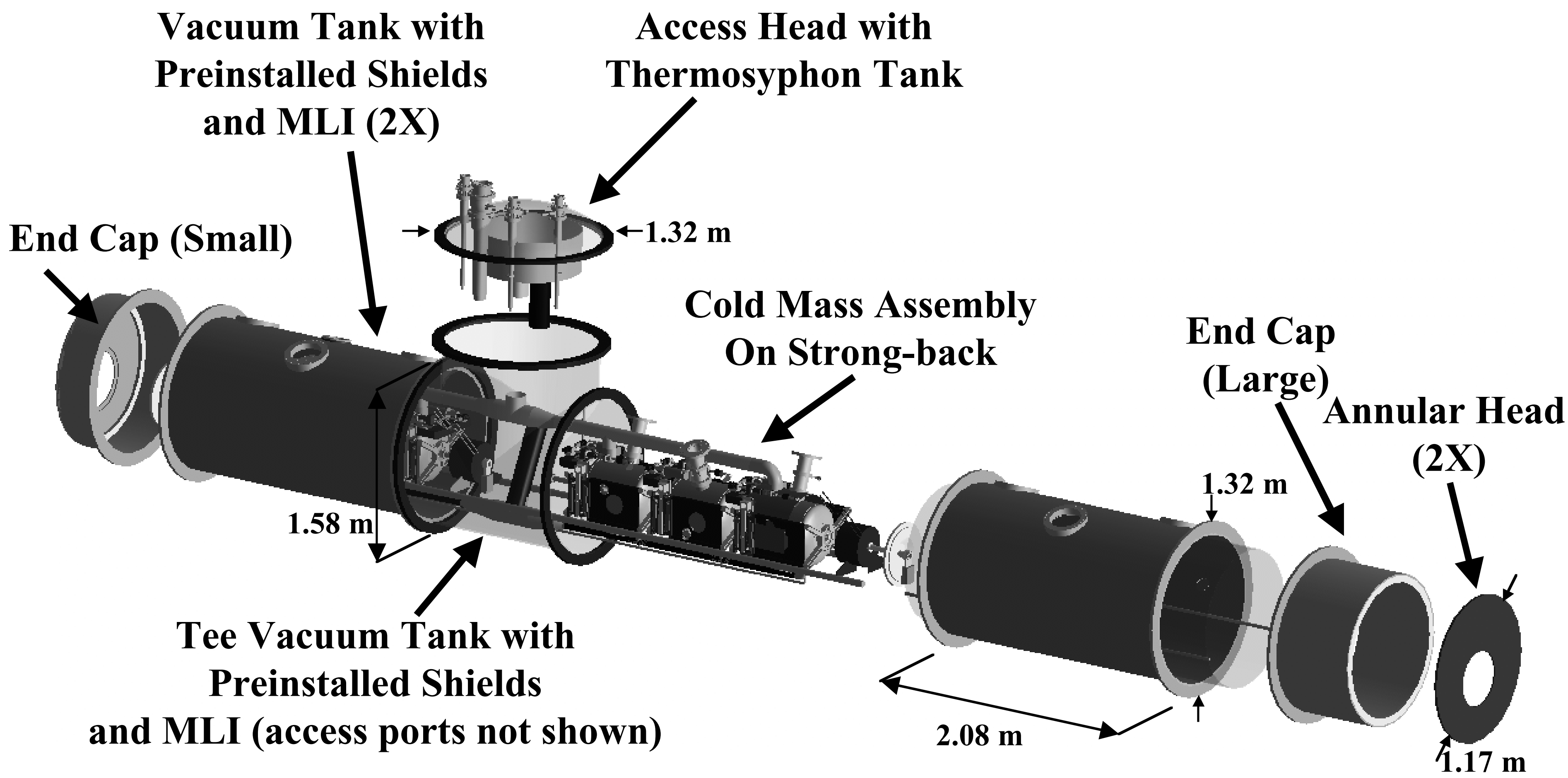
AAA

Spoke Cavity Module Final Assembly

- Insert cold mass assembly into prefabricated Tee section
  - Tee thermal shield (Cu), magnetic shield (Mu metal - 0.040) & MLI blankets (4 @ 15 layers ea.) preinstalled.
- Mount vacuum vessel cylinders to Tee section
  - Thermal shield, MLI blankets, magnetic shield preinstalled (similar to CEBAF s approach).
  - Thermal shield & MLI blanket bridges made.
- Mate couplers/solenoids to vacuum vessel
  - Couplers are only mechanical support for helium vessel assemblies
  - Solenoids use compression post support
    - Similar posts used by SSC, RHIC, LHC
- Remove strong-back
- Install current lead feedthroughs
- Install Tee-section head/internals - make pipe connections
- Install end caps

Spoke Cavity Cryomodule Final Assembly - Figure

AAA



Spoke Cavity Cryomodule Summary

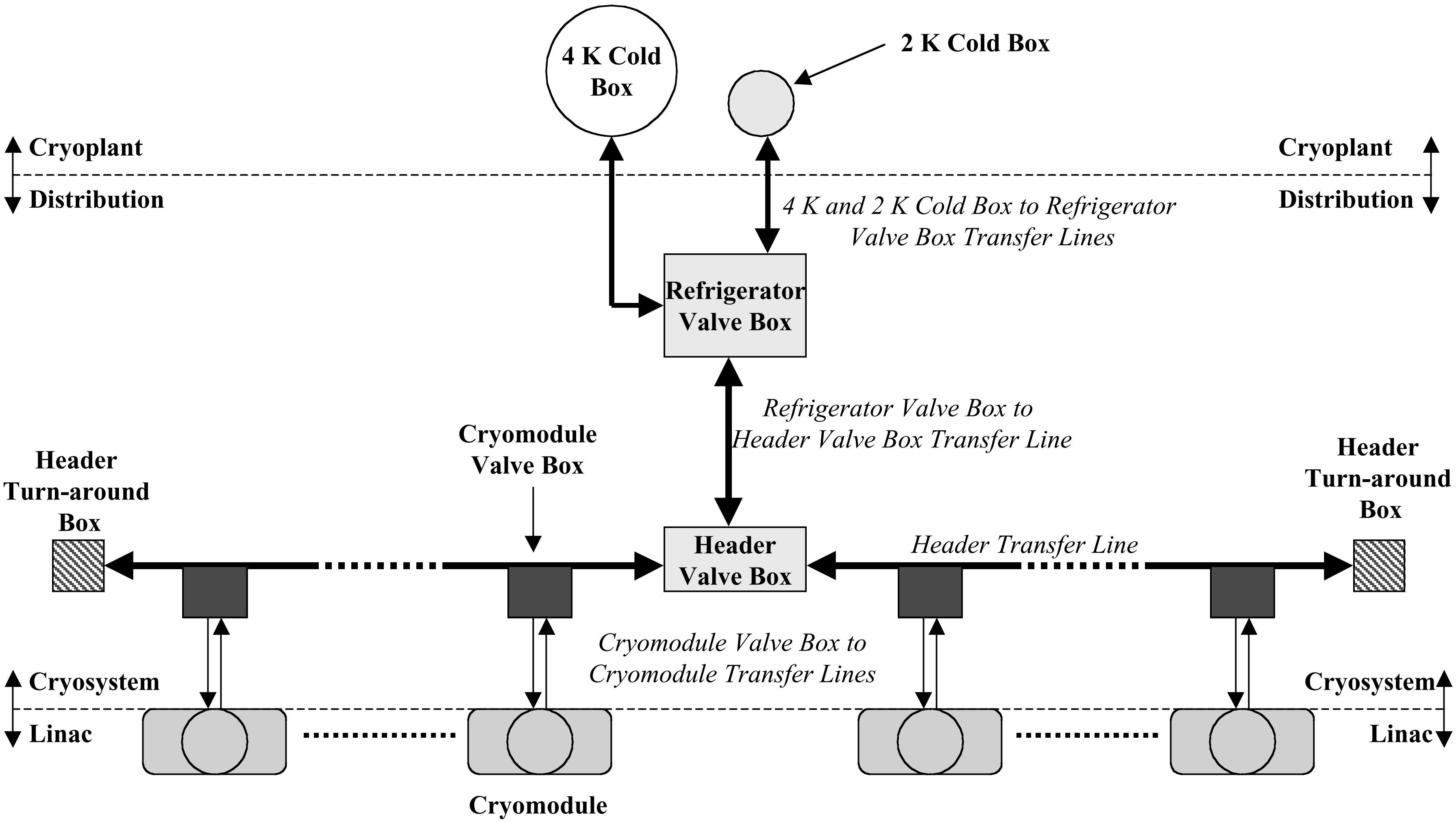
- ¥ Adopted concepts and components from previous programs - minimize risk.
- ¥ Thermosyphon cooling - improves thermal performance.
- ¥ Coupler supported cavities
  - —simplifies assembly,
  - —minimizes thermal shorts, magnetic fringe fields, and
  - —reduces part count.
- ¥ Axial insertion
  - —minimizes clean room time and
  - —simplifies assembly.
- ¥ Similar work has been done by industry.

LEL Refrigeration

AAA

- ¥ Flows
  - —2 K Circuit (0.48 § Cryomodule only)
    - ¨ Supply - 2.2 K, 4 atm
    - ¨ Return - 2 K, 0.028 atm
  - —4.5 K Circuit
    - ¨ Supply - 4.6 K, 4 atm
    - ¨ Return - 4.5 K, 1.286 atm
  - —40 K Circuit
    - ¨ Supply - ~ 38 K, 4 atm
    - ¨ Return - ~ 55 K, 4 atm
- ¥ Equivalent 4.5 K Heat Loads (Based on the APT § = 0.82 Cryomodule)
  - — ~ 13 kW
    - ¨ About 80% the capacity of the CEBAF Cryoplant

LEL Refrigeration - Conceptual Layout



Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 – 12, 2001

ADTF SPOKE CAVITY ED&D PROGRAM

Dale Schrage
LANL/LANSCE-1

ED&D OBJECTIVES

AAA

- ¥ UNDERSTAND & DEMONSTRATE PERFORMANCE OF KEY COMPONENTS OF A SUPERCONDUCTING LOW ENERGY LINAC FOR ADTF
- ¥ VALIDATE COST ESTIMATES
- ¥ VALIDATE SCHEDULE ESTIMATES
- ¥ PREPARE FOR PLANT DESIGN

PROPOSED ED&D PLAN

1a DEVELOP SPOKE CAVITIES FOR THREE DIFFERENT BETAS
1b DEVELOP SPOKE CAVITY POWER COUPLER
1c DEVELOP SPOKE CAVITY TUNER
2 DEMONSTRATE 10 & 55 kW IOT-BASED RF SYSTEMS
3 TEST β = 0.175 SPOKE CAVITY ON LEDA
4 DESIGN/FAB/TEST SPOKE CAVITY CRYOMODULE

ED&D EFFORT ALLOCATION

ACTIVITY	LEAD ORG.	FAB.	TEST
1a SPOKE CAVITIES	LANL	INDUSTRY	LANL
1b SPOKE POWER COUPLER	LANL	INDUSTRY	LANL
1c SPOKE TUNER	LANL	INDUSTRY	LANL
2 RF SYSTEMS	LANL	INDUSTRY	LANL
3 LEDA TEST	LANL	INDUSTRY & LANL	LANL
4 SPOKE CRYOMODULE	PRIME	INDUSTRY	PRIME

SPOKE CAVITY DEVELOPMENT OBJECTIVES

¥ OPTIMIZE THREE CAVITY DESIGNS USING ELECTROMAGNETIC & STRUCTURAL CODES

¥ VALIDATE CAVITY SURFACE TREATMENT PROCESSES & PLAN

¥ VALIDATE ADTF ACCELERATOR GRADIENTS

¥ VALIDATE CAVITY, POWER COUPLER, & TUNER COSTS & SCHEDULE

SPOKE CAVITY DEVELOPMENT PLAN

- DESIGN/FAB/TEST THREE CAVITIES:
  - 2-gap @ $\beta_g = 0.175$
  - 3-gap @ $\beta_g = 0.200$
  - 3-gap @ $\beta_g = 0.340$
- DEVELOP HELIUM VESSEL
- CAVITIES & HELIUM VESSELS FABRICATED IN INDUSTRY

POWER COUPLER DEVELOPMENT PLAN

- ¥ BASED ON HIGHEST POWER REQUIREMENT @ 100 mA
- ¥ DESIGNED @ LANL
- ¥ FABRICATED IN INDUSTRY
- ¥ TEST @ LANL ON MODIFIED APT/ED&D POWER COUPLER TEST STAND
- ¥ AVAILABLE FOR LEDA BEAM TEST

SPOKE TUNER DEVELOPMENT PLAN

AAA

- ¥ ESTABLISH TUNER REQUIREMENTS
- ¥ DEMONSTRATE FAST DE-TUNING OF CAVITIES
- ¥ INTEGRATE WITH CAVITY & HELIUM VESSEL
- ¥ DESIGNED @ LANL
- ¥ FABRICATED IN INDUSTRY
- ¥ TEST @ LANL

AAA

RF POWER SYSTEMS DEVELOPMENT OBJECTIVES

- DEMONSTRATE PERFORMANCE AND RELIABILITY OF LOW COST IOT GENERATORS, POWER SUPPLIES, & TRANSMITTERS

RF POWER SYSTEMS DEVELOPMENT PLAN

- PROCURE & TEST 10 & 55 kW IOT TUBES, POWER SUPPLIES, & TRANSMITTER
- IMPLEMENT RF TEST STAND USING MODIFIED APT/ED&D EQUIPMENT
- 10 KWATT TUBE, POWER SUPPLY, & TRANSMITTER WILL BE AVAILABLE FOR LEDA BEAM TEST (WAVEGUIDE IS IN PLACE)

LEDA BEAMLINE TEST OBJECTIVES

- DEMONSTRATE OPERATION OF SPOKE CAVITY WITH BEAM
- CHARACTERIZE BEAM PROPERTIES
- VALIDATE BEAM DYNAMICS CODES
- DEMONSTRATE VALIDITY OF LLRF FAST ALGORITHMS DEVELOPED UNDER β = 0.64 ED&D

AAA

LEDA BEAMLINE TEST PLAN

¥ DESIGN/PROCURE SIMPLE CRYOMODULE FOR A SINGLE 2-gap @ β_g = 0.175 CAVITY

¥ USE EXISTING LEDA DIAGNOSTICS & ROOM TEMPERATURE QUADRUPOLES

¥ INSTALL ON LEDA BEAMLINE FOLLOWING 6.7 MeV RFQ

¥ OPERATE WITH BEAM UP TO 100 mA

SPOKE CRYOMODULE DEVELOPMENT OBJECTIVES

- ESTABLISH COST OF SPOKE CRYOMODULE
- VALIDATE ASSEMBLY PLAN
- VALIDATE PROJECT SCHEDUE
- VALIDATE PREDICTION OF THERMAL LOADS FOR DESIGN OF CRYOPLANT

SPOKE CRYOMODULE DEVELOPMENT PLAN

- ¥ DESIGN/FAB/TEST PROTOTYPE MULTI-CAVITY CRYOMODULE
- ¥ INTEGRATE WITH CAVITY, POWER COUPLER, & TUNER DESIGNS
- ¥ PROCURE to SPEC & TEST SUPERCONDUCTING SOLENOID

ED&D COST BASIS

AAA

- ¥ LABOR & PROCUREMENTS BASED ON AVERAGE RATES DURING FY2001 - FY2004 @4% INFLATION
- ¥ LABOR HOURS INDEPENDENT OF ORGANIZATION
- ¥ LEDA OPERATIONS COST NOT INLUDED
- ¥ LANL LABOR RATES @ CAPITAL BURDEN RATE (14%)
- ¥ PRIME CONTRACTOR LABOR RATES
- ¥ 30% CONTINGENCY

COST UNCERTAINTIES

- ESTABLISHMENT OF ADTF REQUIREMENTS
- FUNDING PROFILE
- LANL BURDEN RATE:

  14% @ CAPITAL

  42% @ OPERATING
- AVAILABILITY OF PERSONNEL

ED&D SCHEDULE BASIS

AAA

- ¥ LABOR REQUIREMENTS INDEPENDENT OF ORGANIZATION
- ¥ ASSUMES FUNDING IS AVAILABLE WHEN REQUIRED
- ¥ NO SIGNIFICANT STAFF ADDITIONS
- ¥ SOME WORKFORCE LEVELING
- ¥ 25% TIME CONTINGENCY

SCHEDULE UNCERTAINTIES

AAA

- ESTABLISHMENT OF ADTF REQUIREMENTS
- FUNDING PROFILE
- AVAILABILITY OF PERSONNEL
- VENDOR SELECTION PROCESS

ADD FIRST PAGE OF SCHEDULE PLOT

ADD SECOND PAGE OF SCHEDULE PLOT

ADD SUMMARY SCHEDULE PLOT

ED&D COST & SCHEDULE

AAA

ACTIVITY	LEAD ORG.	COST $K	COMPLETION
1a SPOKE CAVITIES	LANL	$8,600	1Q FY04
1b SPOKE POWER COUPLER	LANL	$4,400	2Q FY04
1c SPOKE TUNER	LANL	$1,900	2Q FY04
2 RF SYSTEMS	LANL	$8,200	1Q FY04
ED&D SUBTOTAL	LANL	$23,100	2Q FY04
3 LEDA TEST	LANL	$18,100	3Q FY05
4 SPOKE CRYOMODULE	PRIME	$9,700	3Q FY05
CD3A	DOE	N/A	Aug 23, 2005

EFFECT OF 100 mA REQUIREMENTS

AAA

POWER COUPLERS

20 kW @ 13.3 mA

144 kW @ 100. mA

¥ MORE SPACE CONSTRAINTS IN CRYOMODULE DESIGN:

@20 kW, USE OF 3-1/8 CO-AX INSTEAD OF WR2300 MIGHT BE POSSIBLE

EFFECT OF 100 mA REQUIREMENTS

AAA

RF POWER SYSTEM

- LARGER KLYSTRON GALLERY CROSS-SECTION
- LARGER PENETRATIONS FROM KLYSTRON GALLERY TO TUNNEL
- MORE PENETRATIONS FROM KLYSTRON GALLERY TO TUNNEL

CONCERNS

ED&D PROGRAM HAS NOT BEEN THOROUGHLY PLANNED

- ¥ TRUE TO SOME EXTENT DUE TO LIMITED TIME, PERSONNEL, AND FUNDS
- ¥ PROGRAM DOES ADDRESS MAIN ISSUES:
  - CAVITY PERFORMANCE
  - POWER COUPLER PERFORMANCE
  - TUNER PERFORMANCE
  - HIGH POWER RF SYSTEM PERFORMANCE
  - LLRF SYSTEM PERFORMANCE

CONCERNS

AAA

TECHNICAL RISK

¥ ANL CAVITY HAS BEEN SHOWN TO MEET ADTF TECHNICAL REQUIREMENTS

MEASURED E_0T = 10.5 MVolt/Meter @Q_0 = 5.0 10^8

12.0 MVolt/Meter @Q_0 = 1.5 10^8

REQUIRED E_0T = 4.8 MVolt/Meter @Q_0 = 5.0 10^8

¥ LANL CAVITY DESIGN HAS BETTER RF PARAMETERS (LOWER E_{PEAK}/E_0T & B_{PEAK}/E_0T)

¥ WE WILL EXCHANGE TECHNOLOGY INFORMATION WITH RIA PROJECT

CONCERNS

COMPATIBILITY WITH ADTF SCHEDULE

- ¥ REALISTIC ED&D PROGRAM SCHEDULE (25% CONTINGENCY) WILL PRODUCE NO DELAY IN ADTF PROJECT SCHEDULE
- ¥ SCHEDULE DOES NOT REQUIRE SIGNIFICANT STAFF ADDITIONS
- ¥ SCHEDULE DOES NOT REQUIRE SIGNIFICANT FACILITY REVISIONS
- ¥ SUPERCONDUCTING CAVITIES ARE BUILT IN US, EUROPEAN, & JAPANESE INDUSTRY

CONCERNS

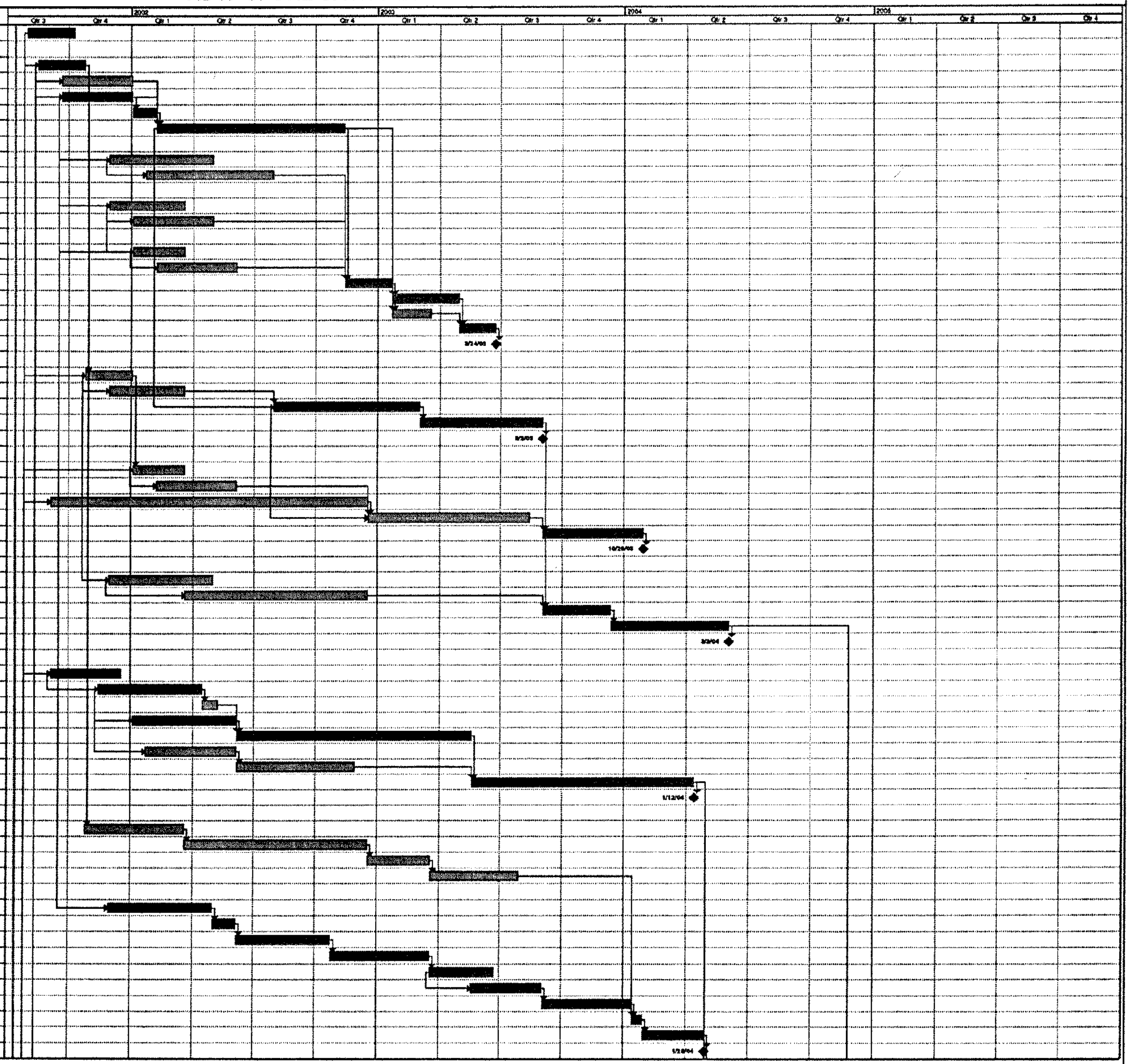
INTEGRITY OF COST ESTIMATE

- ¥ ED&D PROGRAM COST ESTIMATE (30% CONTINGENCY) IS REALISTIC

ADTF SPOKE CAVITY EDnD PROGRAM

Revised: April 6, 2001

ID	Task Name	Duration	Start	Finish
1	Establish Requirements	8 wks	5/1/01	7/9/01
2				
3	Design beta = 0.175 Cavity	8 wks	5/17/01	7/25/01
4	Select Spoke Vendor	12 wks	6/21/01	10/3/01
5	Detail beta = 0.175 Cavity	12 wks	6/21/01	10/3/01
6	Cavity Final Design Review	4 wks	10/4/01	11/7/01
7	Fab beta = 0.175 Cavity (2ea)	30 wks	11/8/01	8/12/02
8				
9	Revise Spoke Test Equipment	16 wks	8/30/01	1/30/02
10	Fab Spoke Test Equipment	20 wks	10/23/01	4/29/02
11				
12	Revise BCP Equipment	12 wks	8/30/01	12/19/01
13	Fab BCP Equipment	12 wks	10/4/01	1/30/02
14				
15	Revise HPR Equipment	8 wks	10/4/01	12/19/01
16	Fab HPR Equipment	12 wks	11/8/01	3/6/02
17	Prepare 1st beta = 0.175 Cavity	8 wks	8/13/02	10/21/02
18	Test 1st beta = 0.175 Cavity	8 wks	10/22/02	1/29/03
19	Prepare 2nd beta = 0.175 Cavity	6 wks	10/22/02	12/18/02
20	Test 2nd beta = 0.175 Cavity	6 wks	1/30/03	3/24/03
21	Release beta = 0.175 Design	0 wks	3/24/03	3/24/03
22				
23	Design beta = 0.20 Cavity	8 wks	7/26/01	10/3/01
24	Detail beta = 0.20 Cavity	12 wks	8/30/01	12/19/01
25	Fab beta = 0.20 Cavity (2ea)	24 wks	4/30/02	12/2/02
26	Prepare/Test beta = 0.20 Cavities (2ea)	18 wks	12/3/02	6/2/03
27	Release beta = 0.20 Design	0 wks	6/2/03	6/2/03
28				
29	Design beta = 0.34 Cavity	8 wks	10/4/01	12/19/01
30	Detail beta = 0.34 Cavity	12 wks	11/8/01	3/6/02
31	Procure Niobium	52 wks	6/5/01	9/16/02
32	Fab beta = 0.34 Cavity (2ea)	24 wks	9/17/02	5/14/03
33	Prepare/Test beta = 0.34 Cavity (2ea)	18 wks	6/3/03	10/29/03
34	Release beta = 0.34 Design	0 wks	10/29/03	10/29/03
35				
36	Design beta = 0.20 Helium Vessel	16 wks	8/30/01	1/30/02
37	Bid/Fab beta = 0.20 Helium Vessel (2ea)	30 wks	12/20/01	9/16/02
38	Install beta = 0.20 Helium Vessel (2ea)	12 wks	6/3/03	9/11/03
39	Prepare/Test beta = 0.20 Cavities (2ea)	18 wks	9/12/03	3/3/04
40	Release Helium Vessel Design	0 wks	3/3/04	3/3/04
41				
42	Select Power Coupler	12 wks	6/5/01	9/17/01
43	Detail Power Coupler	16 wks	8/14/01	1/14/02
44	Power Coupler Final Design Review	3 wks	1/15/02	2/7/02
45	Select Power Coupler Vendor	16 wks	10/4/01	3/6/02
46	Fab Power Coupler (4ea)	36 wks	3/7/02	2/17/03
47	Re-Design Pwr Cplr Test Stand	14 wks	10/23/01	3/6/02
48	Modify Pwr Cplr Test Stand	20 wks	3/7/02	8/26/02
49	Test Power Couplers (4ea)	36 wks	2/18/03	1/12/04
50	Release Power Coupler Design	0 wks	1/12/04	1/12/04
51				
52	Design beta = 0.175 Helium Vessel	16 wks	7/26/01	12/19/01
53	Bid/Fab beta = 0.175 Helium Vessel (1ea)	30 wks	12/20/01	9/16/02
54	Install beta = 0.175 Helium Vessel (1ea)	10 wks	9/17/02	12/18/02
55	Prepare/Test beta = 0.175 Cavities (1ea)	12 wks	12/19/02	4/28/03
56				
57	Design Spoke Tuner	16 wks	8/30/01	1/30/02
58	Spoke Tuner Prelim Des Rev	4 wks	1/31/02	3/6/02
59	Detail Spoke Tuner	16 wks	3/7/02	7/24/02
60	Fab Spoke Tuner	16 wks	7/25/02	12/18/02
61	Test Spoke Tuner	8 wks	12/19/02	3/24/03
62	Redesign Tuner	12 wks	2/18/03	6/2/03
63	Bid/Fab Tuners (2ea)	16 wks	6/3/03	10/13/03
64	Install Tuner on Cavity/Vessel Assy	2 wks	10/14/03	10/29/03
65	Test Tuners	8 wks	10/30/03	1/28/04
66	Release Tuner Design	0 wks	1/28/04	1/28/04



Project: ADTF SPOKE EDnD
Date: 4/12/01

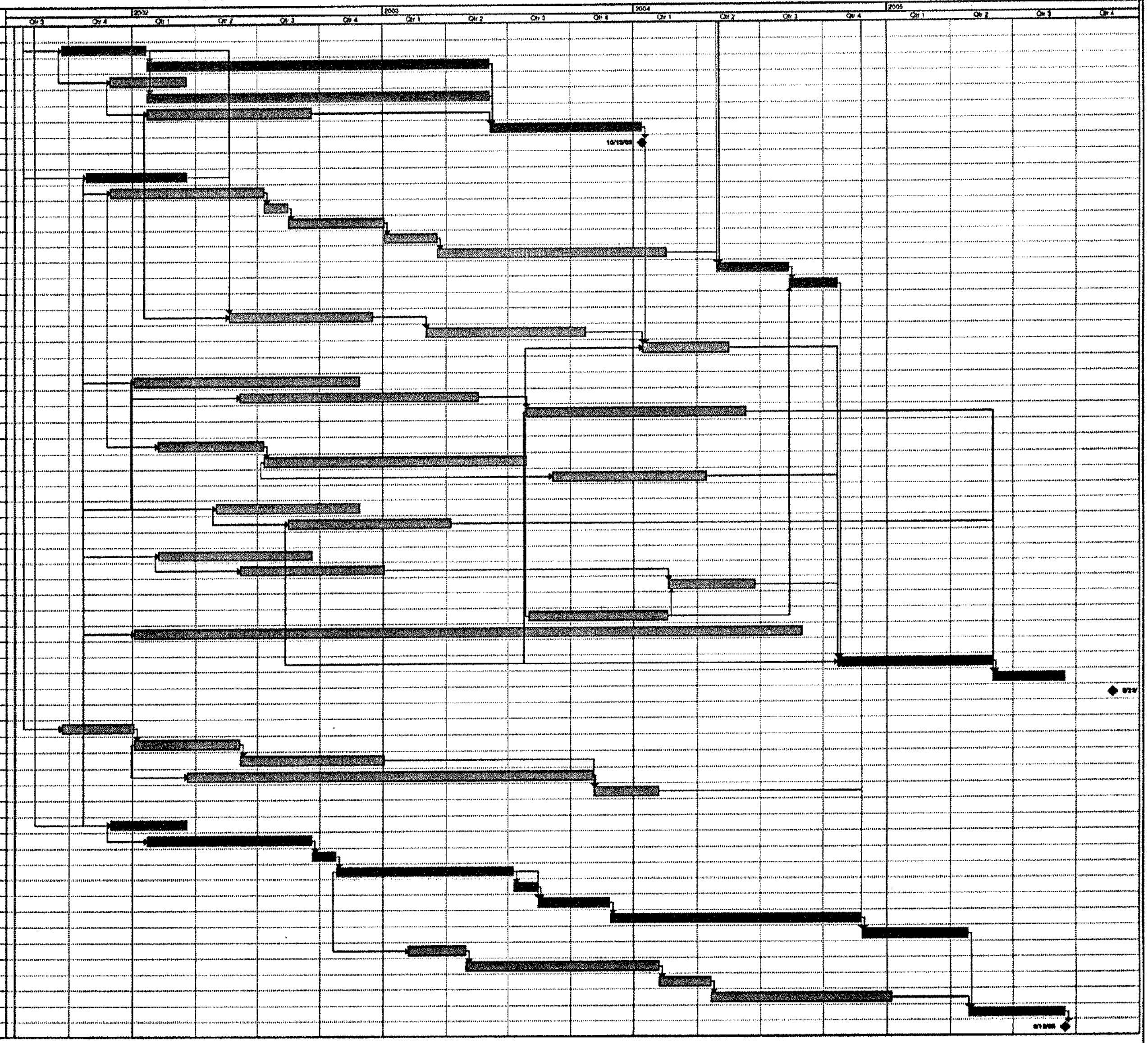
Task | Milestone | Critical

AAA

Revised: April 6, 2001

ADTF SPOKE CAVITY EDnD PROGRAM

ID	Task Name	Duration	Start	Finish
67				
68	Spec 10 kWatt IOT	14 wks	6/21/01	10/22/01
69	Bid/Procure 10 kWatt IOT System	52 wks	10/23/01	3/5/03
70	Spec 55 kWatt IOT	12 wks	8/30/01	12/19/01
71	Bid/Procure 55 kWatt IOT System	52 wks	10/23/01	3/5/03
72	Modify Test Stand	26 wks	10/23/01	6/19/02
73	Test Generators	26 wks	3/6/03	10/13/03
74	Release High Power RF Design	0 wks	10/13/03	10/13/03
75				
76	Spec LEDA Beam Test	16 wks	7/26/01	12/19/01
77	Design LEDA Cryomodule	24 wks	8/30/01	4/10/02
78	LEDA Cryomodule Prelim Des Rev	4 wks	4/11/02	5/15/02
79	Detail LEDA Cryomodule	16 wks	5/16/02	10/2/02
80	Bid LEDA Cryomodule	8 wks	10/3/02	12/18/02
81	Fab LEDA Cryomodule	36 wks	12/19/02	11/17/03
82	Assy LEDA Cryomodule	12 wks	1/29/04	5/12/04
83	Install LEDA Cryomodule	8 wks	5/13/04	7/21/04
84				
85	Des LEDA High Power RF	24 wks	2/19/02	9/16/02
86	Procure LEDA High Power RF	24 wks	12/3/02	7/23/03
87	Install LEDA High Power RF	12 wks	10/14/03	2/16/04
88				
89	Design LEDA LLRF	36 wks	10/4/01	8/28/02
90	Fab LEDA LLRF	36 wks	3/7/02	2/17/03
91	Install/Test LEDA LLRF	35 wks	4/29/03	3/11/04
92				
93	Design LEDA Cryo Supply	16 wks	11/8/01	4/10/02
94	Procure LEDA Cryo Supply	40 wks	4/11/02	4/28/03
95	Install LEDA Cryo Supply	24 wks	8/5/03	1/14/04
96				
97	Design/Fab EPICS	24 wks	1/31/02	8/28/02
98	Install/Test EPICS	24.8 wks	5/16/02	1/8/03
99				
100	Design Diagnostics	24 wks	11/8/01	6/19/02
101	Fab/Test Diagnostics	24 wks	3/7/02	10/2/02
102	Install Diagnostics	12 wks	11/20/03	3/24/04
103				
104	Remove CCDTL Beam Line	24 wks	5/1/03	11/19/03
105	HCPs & Permitting	104 wks	10/4/01	5/31/04
106				
107	LEDA Checkout & Commissioning	24 wks	7/22/04	3/2/05
108	LEDA Beam Test	12 wks	3/3/05	6/15/05
109	CD3A	0 wks	8/23/05	8/23/05
110				
111	Spec SC Solenoids	12 wks	6/21/01	10/3/01
112	Design SC Solenoids	16 wks	10/4/01	3/6/02
113	Bid/Procure SC Solenoids (2ea)	24 wks	3/7/02	10/2/02
114	Des/Fab Solenoid Test Equipment	63 wks	12/20/01	8/1/03
115	Test SC Solenoids (2ea)	12 wks	8/4/03	11/6/03
116				
117	Spec Spoke Cryomodule	12 wks	8/30/01	12/19/01
118	Design Spoke Cryomodule	26 wks	10/23/01	6/19/02
119	Spoke Cryomodule Prelim Des Rev	4 wks	6/20/02	7/24/02
120	Detail Spoke Cryomodule	26 wks	7/25/02	4/9/03
121	Spoke Cryomodule Final Des Rev	4 wks	4/10/03	5/14/03
122	Bid Spoke Cryomodule	12 wks	5/15/03	8/27/03
123	Fab Spoke Cryomodule	40 wks	8/28/03	8/25/04
124	Assy Spoke Cryomodule	16 wks	8/26/04	1/26/05
125	Design Cryosupply	6 wks	11/7/02	1/29/03
126	Bid/Fab Cryosupply	33 wks	1/30/03	11/6/03
127	Install Cryosupply	6 wks	11/7/03	1/20/04
128	Design/Fab Cryomodule Test	30 wks	1/21/04	10/7/04
129	Test Spoke Cryomodule	16 wks	1/27/05	6/15/05
130	Release Cryomodule Design	0 wks	6/15/05	6/15/05



Project: ADTF SPOKE EDnD
Date: 4/12/01

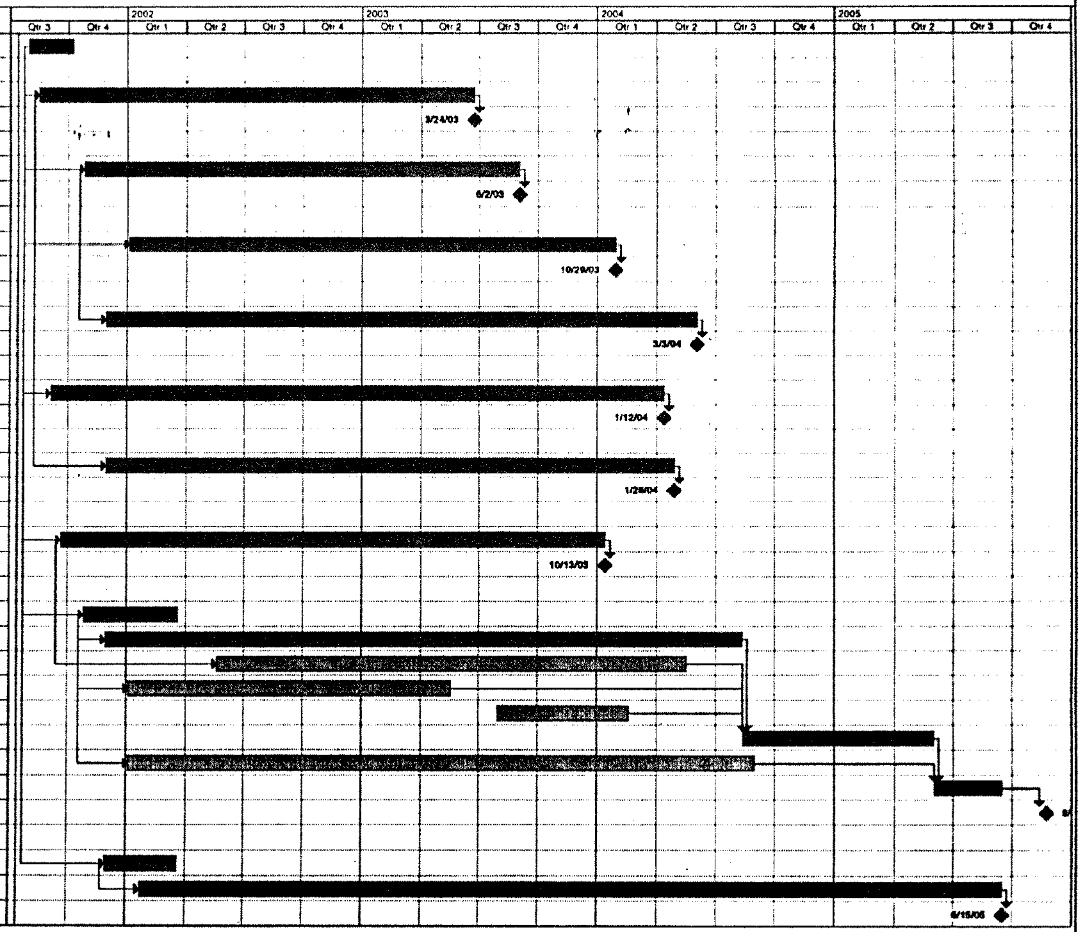
Task | Milestone | Critical

ADTF Linac Review, April 10-12, 2001

ADTF SPOKE CAVITY EDnD PROGRAM

Revised: April 6, 2001

ID	Task Name	Duration	Start	Finish
1	Establish Requirements	8 wks	5/1/01	7/9/01
2				
3	Design/Fab/Test beta = 0.175 Cavity	72 wks	5/17/01	3/24/03
4	Release beta = 0.175 Design	0 wks	3/24/03	3/24/03
5				
6	Design/Fab/t\Test beta = 0.20 Cavity	72 wks	7/26/01	6/2/03
7	Release beta = 0.20 Design	0 wks	6/2/03	6/2/03
8				
9	Design/Fab/Test beta = 0.34 Cavity	82 wks	10/4/01	10/29/03
10	Release beta = 0.34 Design	0 wks	10/29/03	10/29/03
11				
12	Design/Fab/Test beta = 0.20 Helium Vessel	98 wks	8/30/01	3/3/04
13	Release Helium Vessel Design	0 wks	3/3/04	3/3/04
14				
15	Design/Fab/Test Power Coupler	102 wks	6/5/01	1/12/04
16	Release Power Coupler Design	0 wks	1/12/04	1/12/04
17				
18	Design Spoke Tuner	94 wks	8/30/01	1/28/04
19	Release Tuner Design	0 wks	1/28/04	1/28/04
20				
21	Spec/Procure/Test IOTs	92 wks	6/21/01	10/13/03
22	Release High Power RF Design	0 wks	10/13/03	10/13/03
23				
24	Spec LEDA Beam Test	16 wks	7/26/01	12/19/01
25	Design/Fab/Assy LEDA Cryomodule	106 wks	8/30/01	5/12/04
26	Des/Fab/Install LEDA High Power RF	78 wks	2/19/02	2/16/04
27	Design LEDA LLRF & EPICS	52 wks	10/4/01	2/17/03
28	Remove CCDTL Beam Line	24 wks	5/1/03	11/19/03
29	Instal/Checkoutl Equipment on LEDA	32 wks	5/13/04	3/2/05
30	HCPs & Permitting	104 wks	10/4/01	5/31/04
31	LEDA Beam Test	12 wks	3/3/05	6/15/05
32	CD3A	0 wks	8/23/05	8/23/05
33				
34	Spec Spoke Cryomodule	12 wks	8/30/01	12/19/01
35	Design/Fab/Test Spoke Cryomodule	144 wks	10/23/01	6/15/05
36	Release Cryomodule Design	0 wks	6/15/05	6/15/05



Project: ADTF SPOKE EDnD
Date: 4/12/01

Task | Milestone ◆ | Critical

e:\atw\cost\adtfacednds.mpp

AAA

Advanced Accelerator Applications (AAA)

ADTF Linac Design Review

April 10 — 12, 2001

SUMMARY OF ADTF DESIGNS
100 mA DESIGN IMPACTS
COST AND SCHEDULE COMPARISONS

Rich Sheffield

SUMMARY OF SC and NC DESIGN COMMON FEATURES

¥ Physical layout of accelerator does not change in going from 13 mA to 100 mA

¥ Current-independent focusing-lattice designs (0-13 mA).

¥ Meets schedule for beam operations.

¥ Capital costs effectively the same.

¥ The injector as is currently operational would be the major source of faults. ED&D is required to improve injector performance.

¥ An average real estate gradient of ~ 1 MV/m.

SUMMARY OF NC DESIGN FEATURES AND ISSUES

¥ **Features :**

- —CCDTL linac design status is further along than for the spoke cavity.
- —CCLs has been operated CW (Chalk River and NBS).
- —CCDTL is a combination of a CCL and a DTL.
- —We have a high degree of confidence that CCDTL thermal issues have been resolved.
- —We expect better beam quality preservation resulting in less emittance growth and halo formation. This effect is most pronounced for the 100 mA operation.
- —The magnets are outside of the structure and are easily accessible for maintenance.
- —The oxygen free copper structure is robust and will not be susceptible to failure.
- —Present design allows rapid restoration of RF power following an RF system failure.

¥ **Issues:**

- —Hot model test of CCDTL sections required.
- —High-power RF switch development required.
- —Hot model test of CCL section should be done.

SUMMARY OF SC DESIGN FEATURES AND ISSUES

AAA

- Features:
  - SC linac requires significantly lowers the total linac (0 - 600 MeV) AC power at 13 mA (23 MW vs. 80 MW, a savings of 57 MW).
  - Independently controlled RF modules (installed redundancy) allow adjusting phasing and amplitude of RF modules to compensate for faults of individual cavities, klystrons, or focusing magnets.
  - The β=0.48 elliptical cavity design can be adapted from the prototyped β=0.64 cavity design.
  - Larger bore radius relaxes alignment and steering tolerances, as well as reducing the possibility of beam loss.
  - Stable operating temperatures reduces or eliminates out-of-lock beam trips.
  - More CW operating experience exists for SC linacs than for NC linacs.
  - Each differing β SC structure would have generic replaceable modules.
  - The cryoplant is already extant since the majority of the linac (211 MeV to 600 MeV) is superconducting.
- Issues:
  - Prototype power coupler, cavity tuner, and cryomodule for SC spoke resonators must be completed.
  - Are stiffeners required for the β=0.48 elliptical cavity design?
  - SC design is not as far along as for NC design.

BEAM CURRENT CONSIDERATIONS

AAA

- Simultaneous operation of multiple beamlines is expected later in the program. ED&D program required to develop reliable (i.e. safe) beam sharing technology such that we cannot overdrive a target station.
- Design both normal conducting and superconducting for 100 mA capability.

IMPACT OF 100 mA, 1 GeV REQUIREMENT ON ADTF DESIGN ASSUMING NO MAJOR REDESIGN

- **Normal conducting accelerator cavities (CCDTL and CCL): Very limited impact. The RF power coupling iris in the copper structure has to be sized for the operational current. The coupling iris will not be re-machined if 100 mA operation is required, so the RF has to be sized for the extra reflected power at 100 mA current (4.5 MW extra out of 44 MW).**
- **For all superconducting cavities (spoke, β=0.48, and β=0.64): Very limited impact. We do not propose to redesign the power coupler, but have the coupler sized for 100 mA operation. By adjusting the coupler penetration in the cavity, the coupling can be matched to the beam current.**
- **Facilities: Minimal impact.**
  - **Klystron gallery, waveguide penetrations, and permanently installed utilities need to be sized for additional klystrons.**
  - **Building layout must be compatible with a high energy extension.**
  - **Negates possibility for beamline spurs at intermediate energies.**

PROPOSED CAVITY ED&D PLAN

AAA

- Sections 1 and 2 of CCDTL: Finish fabrication, install, and operate on LEDA.
- 100 MeV CCDTL section: Construct and test full-power copper cavity.
- CCL Section: Construct full-power copper section.
- β =0.48 cavity: Fabrication of 5-cell cavity. RF test cavity in cryo-laboratory.
- Spoke cavity: Fabrication of cavities, power coupler, and tuner. RF test completed cavity. LEDA test.

INCREMENTAL COST AND SCHEDULE SUMMARY

ADTF Configuration	Yearly Op Cost Impact*	Cap Cost (~$0M AES Difference)	ED&D cost	Sched. Impact#	Notes
ADTF baseline = optimized 13-mA design with CCDTL and CCL	+$0.0M	+$2M(b)	+$4.4M(a)	+0yrs	NC design further along
Dev. program covering all options (optional testing)		+$2M(b) +$9.7M(d) =+$11.7M	(a)+(c)+(d) = +$30.1M (+$51.0M)	+1yrs	
Replace CCL with β=0.48 SCRF (optional testing for β=0.48)	-$9.6M		+$4.4M(a) +$2.7M(c) =+$7.1M (=+$9.9M)	+0yrs	Cuts operating costs, reduces number of beam interrupt faults
Replace CCDTL with SCRF Spoke Cavities and CCL with β=0.48 SCRF (optional testing: LEDA and β=0.48)	-$16.3M	+$9.7M(d)	$22.9M(d) +$2.7M(c) =+$25.6M (=$46.5M)	+1yrs	Cuts operating costs, rides through faults, gives greatest operational flexibility

*Total linac operating costs ~ $23M/yr (82%avail & 90%sched); # Assuming mid-03 start of final design on linac sections; Dev. cost for: (a)=CCDTL, (b)=CCL, (c)=0.48, (d)=spoke; 30% cntgcy

Superconducting Solenoid Modeling **4/12/01**

We started our effort to design a superconducting linac last fiscal year as part of the Accelerator Transmutation of Waste Project. That design included the use of superconducting solenoids in the cryomodules to focus the beam. As part of this effort we did some preliminary modeling of the solenoid geometry and examoned the effects of using a field clamp to reduce the fringe field seen by the nearby accelerating cavity (spoke cavity). The results of our modeling effort to date are given in the attached memorandum.

We chose to model only the Section 1 solenoid with the hope that this would allow us to draw general conclusions about the effectiveness of field clamping throughout the machine. We assumed the maximum field required for that design layout, namely 5.5 T. You will notice from our present parameter table that the solenoids will operate over a range of values (1.8T — 5.6T) throughout the machine, with most magnets operating well below the maximum. The solenoid length that was used is 15 cm. The solenoid ID is assumed to be 7 cm to allow room for the beam pipe. A cavity bore diameter of 6 cm was assumed. We presently have a 4-cm bore diameter in Section 1 as a result of MAFIA cavity simulations and the desire to maintain a high transit-time factor in the β=0.175 spoke cavities. In our example, the distance between the end of the solenoid and the cavity was 10 cm, based on a previous, non-realistic cryomodule layout. You will notice that this distance has now been increased to 30 cm and based on the modeling results, should eliminate any concerns about flux trapping in the cavities assuming field clamping is used.

We have also communicated with SC solenoid vendor. They claim that another option would be to use bucking coils at the ends of the solenoid. They did some modeling using the geometry of one of their solenoids that would meet our requirements and concluded that they could reduce the field on-axis to below 0.1T. I assume, as is the case in our results, that the field at the surface of the cavity is orders of magnitude lower. This was a verbal communication and so I don t have their modeling data to compare with the field clamp results.

If you have any further questions, please feel free to contact me.

Bob Garnett
505-665-2835
rgarnett@lanl.gov

Los Alamos
NATIONAL LABORATORY
memorandum

Los Alamos Neutron Science Center, LANSCE-1
Accelerator Physics and Engineering Group

To/MS: Distribution
From/MS: Robert Garnett, H817
Phone/Fax: 5-2835/5-2904
Symbol: LANSCE-1:00-090
Date: September 28, 2000
Email: rgarnett@lanl.gov

SUBJECT: SC SOLENOID MODELING FOR ATW

We have proposed using superconducting solenoids for transverse focusing of the beam in the ATW Advanced Superconducting Design Example [1]. Figure 1 shows the proposed cryomodule layout. As can be seen, two of the cavities in the cryomodule are positioned closely to a solenoid. In a previous memorandum [2] we discussed the effects of stray magnetic fields from the SC solenoids on the performance and operation of the SC cavities. In that paper we used anlytical expressions to estimate the stray magnetic fields that would be seen by a SC cavity for the apertures and distances we have selected. Based on our results, it will be necessary to modify our advanced ATW SC design example. David Barlow (LANSCE-1 magnet physicist) believes that it may be possible to substantially reduce the ambient magnetic fields through the use of field clamps on the solenoids. Below we present the results of his first computer modeling attempt to calculate the stray fields and the effectiveness of using a field clamp.

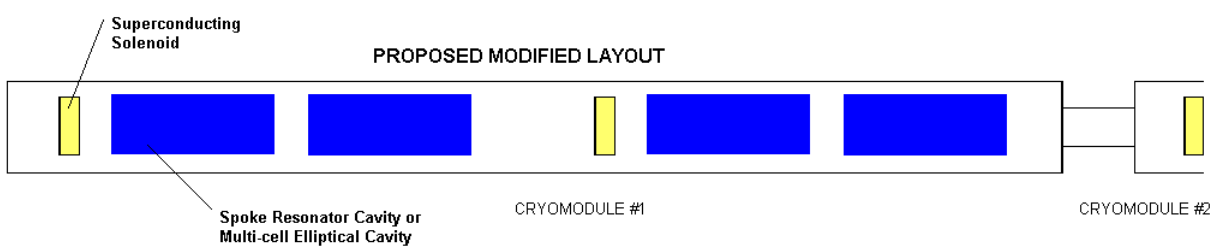


Figure 1 – Proposed ATW SC Design cryomodule layout.

The SC solenoid specified for Section 1 of our design example was modeled. Figure 2 shows the geometry and dimensions used for the calculations. The ID of the coil is assumed to be 7.0 cm to allow room for the 6.0 cm OD beam pipe. A 6.0 cm cavity bore diameter has also been assumed here. The solenoid length is assumed to be 15 cm. The closest distance between the end of the solenoid and the cavity is assumed to be 10 cm (At z= 17.5 cm where z= 0 at the solenoid center).

For modeling purposes, the field clamp material is assumed to be C1006 low-carbon steel. Figure 3 shows a comparison between the analytical solution, and the finite-element analyses with and without a field clamp, of the on-axis magnetic field as a function of distance from the solenoid center. The analytical calculation assumes an infinite boundary condition ($z = \infty$). The finite-element calculations assume boundaries at a radius of r= 22 cm and z=50 cm. This difference in boundary conditions leads to the observed disagreement between the analytical and the finite element calculations for the case with no field clamp. The field clamp being considered is more of a yoke than a clamp. Figure 4 shows an expanded view in the region of interest near the SC cavity (z=17.5 cm). At z= 17.5 cm, the field clamp appears to reduce the stray fields from 0.23 T to 0.07 T, a factor of approximately 3.3 reduction. Figure 5 shows the z-component of the field at z= 17.5 cm as a function of radius (R). Note the even more dramatic reduction in stray magnetic field off-axis with the clamp.

Our conclusion, therefore, is that the addition of a field clamp should be able to dramatically reduce the stray magnetic fields seen by the SC cavities in the linac to levels well below the required 0.1 T while the magnets are on. Magnetic shielding will still be required to shield the cavities from the Earth's magnetic field and from the residual magnetization of the steel in the clamp (approximately 10 Gauss) so that the cavities will not trap magnetic flux as they are cooled through the SC transition.

References:

[1] R. Garnett, "ATW Advanced Superconducting Design Example," Los Alamos National Laboratory Memorandum, LANSCE-1:00-55, July 10, 2000.
[2]] R. Garnett, "ATW Advanced Superconducting Design Example and the Use of SC Solenoids," Los Alamos National Laboratory Memorandum, LANSCE-1:00-070, August 16, 2000.

RWG:amg

Figure 2 – Geometry and dimensions used for the finite-element modeling of the SC solenoid and field clamp.

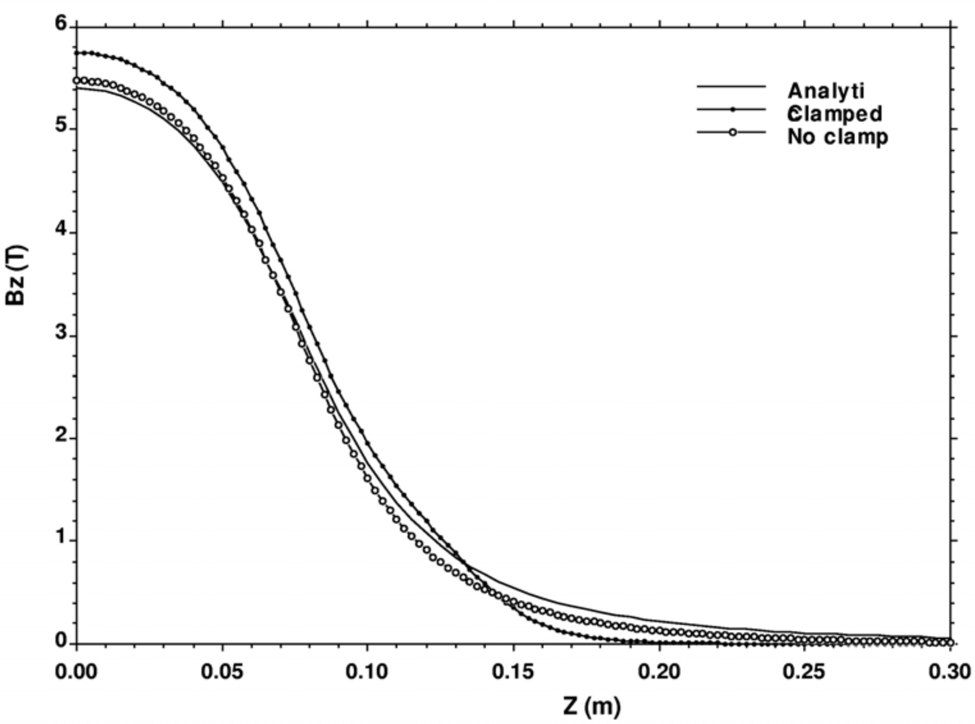


Figure 3 – Comparison of the analytical and finite element solutions for the on-axis magnetic field as a function of z-distance from the solenoid center.

Figure 4 – Expanded view comparison of the solutions with and without a field clamp near the position of the nearest SC cavity (z=17.5 cm).

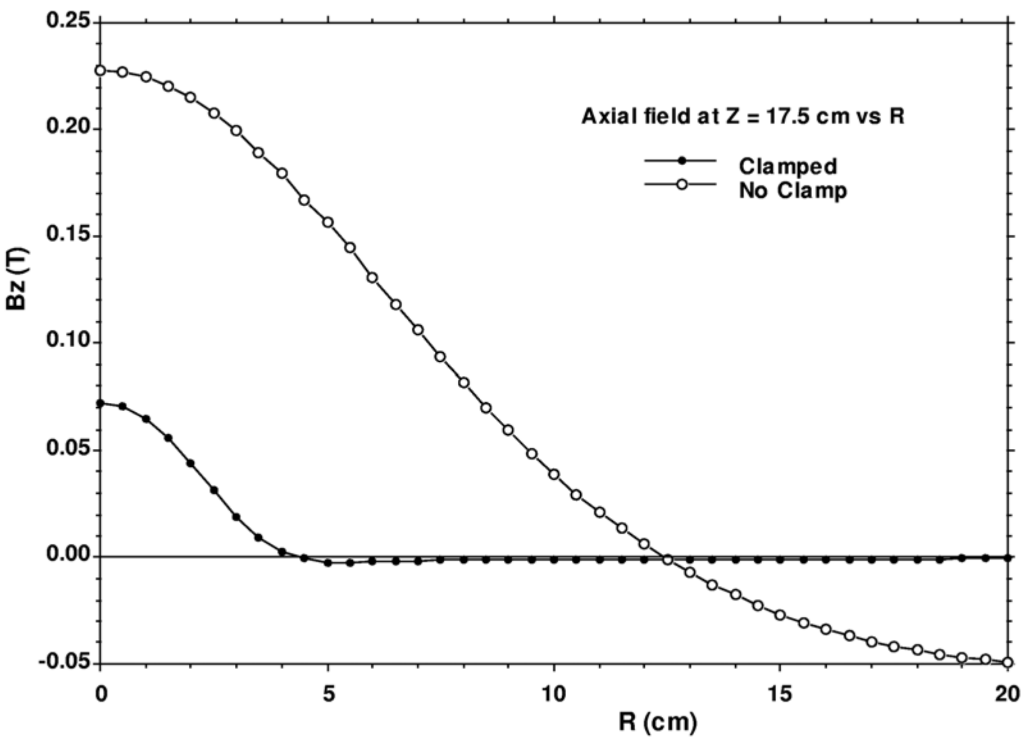


Figure 5 – Axial (z) component of the magnetic field at z= 17.5 cm as a function of radius (R)

Distribution:
T. Bhatia, LANSCE-1, H817
B. Blind, LANSCE-1, H817
D. Chan, APT-TPO, H816
P. Colestock, LANSCE-9, H851
A. Jason, LANSCE-1, H817
F. Krawczyk, LANSCE-1, H817
R. LaFave, LANSCE-1, H817
G. Lawrence, APT-TPO, H816
W. Lysenko, LANSCE-1, H817
T. Mottershead, LANSCE-1, H817
F. Neri, LANSCE-1, H817
G. Neuschaefer, LANSCE-1, H817
D. Rees, SNS-02, H827
L. Rybarcyk, LANSCE-1, H817
R. Sheffield, APT-TPO, H851
D. Schneider, APT-TPO, H816
D. Schrage, LANSCE-1, H817
S. Schriber, LANSCE-DO, H845
V. Smith, APT-TPO, H816
T. Wangler, LANSCE-1, H817
LANSCE-1 File

Frequency Change With Tip Position

- Q_{ext} (100 mA) = 1.9e5 ⇒ tip @ 7 mm (back into pipe)
- Q_{ext}(13.3 mA) = 1.4e6 ⇒ tip @ 20 mm (back into pipe)

- Frequency (7 mm) = 346.65 MHz
- Frequency (20 mm) = 346.21 MHz
- Δf = 440 kHz « 3 times nominal excursion of 55 mils

- While this might be feasible at 4 K, it uses all margin, thus it is more prudent to add provisions for re-setting the cavity frequency if the beam-current should be changed.
- The procedure could use a turn-buckle on the tuning rods and the possibility to re-center the tuner position to re-gain the full tuning range.

TPO-RGN-1003

AAA

AAA/APT/ATW External Review
April 10-12, 2001

Bill Herrmannsfeldt, SLAC, chair

Mike Cornwall, UCLA

Nikolai Mokhov, FNAL

Todd Smith, Stanford U.

Jerry Watson, ret.

Agenda

- APT/ATW REQUIREMENTS, Bill Herrmannsfeldt
- SCRF AND SPOKE RESONATOR, Todd Smith
- PROGRAM RECOMMENDATIONS, Mike Cornwall
- COSTS AND RELIABILITY, Bill Herrmannsfeldt
- PROJECT PLANNING, Jerry Watson
- LEDA, Jerry Watson
- SUMMARY, Bill Herrmannsfeldt

APT/ATW Requirements

- Maintain a viable backup technology until tritium production in commercial light water reactors is demonstrated.
- Safe long-term storage of spent fuel from commercial nuclear power generating stations.
- Rebuilding the national infrastructure needed to support the advancement of nuclear science and technology.
- Provide isotopes for medical and commercial uses.

ERC Recommendation:

- Use β=.48 SCRF structures in place of the CCL.
- Use superconducting spoke resonators in place of (most of) the CCDTL.

The system advantages of SCRF (power consumption, large bore, reliability, …) appear to be compelling.

Progress on the spoke resonator cavities and associated systems has been astonishing.

Personal Concerns:

- BBU and HOM couplers
- Multipacting
- Focusing solenoid fringe fields
- Cold motors for tuning
- Possible over-optimization of spoke cavity resonator geometry
- Spoke cavity coupler orientation (up vs. down)
- Spoke cavity cryomodule details-alignment and suspension.

ADTF PROGRAM: SC VS NC

AAA

- ERC endorses replacement of CCL with SC elliptical-cavity modules
- CCDTL vs spoke resonator:
  - ANL legacy is useful; LANL optimization seems very successful so far
  - Low-energy CCDTL encountered cooling problems; probably cured; concerns remain
  - CCDTL effort well-done, inadequately supported

SC VS NC

- ERC recommendation:
  - Consider adopting spoke design as baseline from RFQ to 100 MeV
  - Consider a low-energy CCDTL as transition section from RFQ to spoke (better beam dynamics)
  - Carry on appropriate LEDA experiments with this CCDTL
  - No present need to build 100 MeV CCDTL hot model

INTEGRATING ACCELERATOR AND T/M

AAA

- Few T/M people; little T/M discussion
- **Reliability:** Accelerator designers very responsive to beam trip issues; T/M people must now respond
- Likely that necessary reliability can be achieved either with NC or SC
- LAMPF trip data misleading (Cockroft-Walton)
- Integrated effort an excellent opportunity to revitalize national nuclear infrastructure

ERC RECOMMENDATION

- Establish joint meetings and efforts with T/M people and labs (e.g., ANL); project needs people with combined expertise in both fields
- Pay real attention to the issue of revitalization of nuclear energy infrastructure
- Put the reliability issue to rest soon; it need not be a driving issue in accelerator design

Redundancy and Extra Costs

- Important to reduce the cost of the ADTF.
- Stress best possible conservative design.
- Get reliability by component quality.
- Delay costs for redundancy until clear need
- Delay costs for APT until need is known.

SUBCRITICAL MULTIPLIER

AAA

- Setting requirements a two-way road
- Reactor mitigation options:
  - Reduce peak temperature
  - Reduce temperature differential
  - Reduce tubewall thickness
  - Improve ASME analysis
- Continue target optimization; APT target is mostly good

LEDA Results

AAA

- APT goal achieved -- 100 mA with good beam quality
- Beam characterization well underway at APT and ATW currents
- Long runs will identify improvements to reliability/availability
- Tremendous advantage for ADTF -- tested injector reduces ED&D

Project Planning Comments

- Need TPO Leader Position filled
- Need reactor team integrated in planning
- Decide who is in charge of baseline and physics design
- Choice of baseline and physics design needs to be done on schedule
- After baseline choice have independently-led value engineering exercise